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The Place of the DFR

ON November 14 the fast reactor at Dounreay went critical and the long programme of operational experimentation designed to evaluate the potentialities of the system began. Much valuable experience has, of course, already been obtained with the critical assemblies at Harwell, during the design phase and over the commissioning period. When brought up to the full design power of 60 MW(t) (and this will take many months) the reactor will be the largest fast system in the world.

Although this in itself may be valuable for prestige purposes it is more likely to be an embarrassment to those who are required to operate it. Dounreay is an example of trying to run before we had really learned to walk, a policy which if it pays off—as it did at Calder—excites only admiration, but which can lead to great difficulties in the event of setbacks. Many of the physics and engineering problems of fast reactor technology were recognized before the DFR was begun, but not all the problems were appreciated and we were particularly ignorant of the more vital aspects of cross-section dependence upon energy and the degradation of the spectrum that results as the core is diluted with fertile material and coolant.

Although the discovery of large uranium deposits throughout the world has largely removed all urgency from breeding *per se* a British electricity programme based upon gas-cooled reactors still needs some outlet for its plutonium production and the fast reactor is certainly one reactor system that should be able to burn plutonium efficiently. It will be some years before we in this country gain any practical experience of this, as the first Dounreay core is U^{235}, and it will probably be 1963 or 1964 before a plutonium core replaces it.

The fast reactor is, however, not the only reactor system which can use plutonium as a fuel, although it may ultimately prove to be the most economical. We must know much more about the physics and metallurgy of plutonium and its compounds before the optimum type (if one exists) can be established. It would be unfortunate if our whole development programme in regard to this fuel were geared solely to the fast reactor and other alternatives ignored. At one time the positive temperature coefficient resulting from any significant concentration of plutonium in Calder-type reactors was enough to rule its application out, but there are other thermal systems and in any case we are learning to live with positive coefficients. The integrated control problems in thermal reactors may be found to be less than those implicit in large fast reactor operation.

In the evidence given to the Select Committee there would appear to be differing approaches to the system by the groups and the CEGB. Whereas Sir Christopher Hinton placed the greatest emphasis on FR development, the groups mainly chose either to ignore it, or pleaded ignorance of its potentialities. The industrial view implies that the U.K. AEA has yet to take British industry into its confidence—a situation that requires remedying now during these early days of start-up—and also that industry considers that not enough is yet known for any definite opinion to be given. Certainly a decision to regard the fast reactor as the only plutonium burner would not be received with enthusiasm, as systems developed overseas—in which the groups are rapidly developing expertize through various commercial link-ups—may well prove adaptable.

The CEGB would also appear to regard the fast reactor as offering the lowest cost potential. Such a view must be based on a number of bold assumptions. It could well be that, as more becomes known, the engineering complexity will raise the capital cost per kW installed above the thermal reactor figure in spite of much increased specific ratings. Furthermore, the practical conversion ratio could turn out to be only marginally greater than unity in large systems and, partly in consequence, the fuel cycle costs high.

On the other hand, the fast reactor could be the reactor of the late 1970s, and while the DFR may not represent the ideal experimental facility, it will allow the U.K. to play a significant part in the world-wide development that the system is receiving. Such an international effort is almost certain to ensure that the reactor has some place in the future power complex, but its exact rôle has still to be assessed. It is important that during this evaluation period due attention is given to the development of such vital engineering components as pumps, heat-exchangers, traps, etc.—surely a task for industry.

International Collaboration Circle

THE Euratom representatives will have returned to Brussels well pleased with the success of their negotiations in London. We trust that they are also duly appreciative of the co-operation that has been extended to them and of the generosity of the United Kingdom. In addition to the participation previously organized in the Dragon project they are now to be given access to experience gained on the DFR and a meeting will be held this month to agree conditions for inclusion in the AGR project. The change of heart in official circles in this country should now be self-evident and Euratom cannot now cavil at U.K. dilatoriness, nor protest that the U.K. AEA is not implementing the agreement signed last February in a thoroughly concrete manner. It now rests with Euratom to see that there is some reciprocity of action: they cannot indefinitely expect to be solely on the receiving end.

Continued exclusion of Euratom would have been somewhat illogical in view of the comprehensive nature of our own exchange agreements with the U.S.A. and the U.S.-Euratom R and D programme. The bigger surprise is perhaps the extension of our agreement with the U.S.A. to cover AGR developments (briefly reported in last month's issue, p. 466). Twelve months ago this would have appeared to be a most improbable move and strong objections would have been made by the groups. So extensive however is the liaison now between British and American companies that the competition between the U.S.A. and ourselves is rapidly becoming one of price only, and not one of system. Indeed the groups look to this arrangement to finally set the seal on propaganda against the gas-cooled reactor as a type rather than because of any economic considerations.

The arrangement with the U.S. contains safeguards which will allow certain aspects of detailed engineering technique to remain confidential, although we suspect that this proviso is of more academic than practical importance; once teams become thoroughly acquainted then very little remains secret. There is too, at present, an important difference in approach between the two countries, the U.S. being more concerned with helium as coolant and the U.K. with CO_2. Similarly the U.K. is likely to place much greater emphasis on beryllium canning and the U.S. on steel, although the tie-up between Tube Investments and the Superior Tube Company of America implies that there will now be a centre in the U.S.A. for beryllium tube production of reactor quality.

The year 1960 then, opens with the major western organizations collaborating at both government and industrial levels on nearly all aspects of reactor development. Whatever the immediate prospects for reactor sales may be, this country, with its long tradition of low cost high quality manufacture, can look forward to strengthening its hold on the ultimate world markets based upon solid partnerships distributed over the globe—a much more comfortable position than the one which would have resulted from the splendid isolation so vigorously promoted only three years ago.

Sea Disposal

THE Monaco conference on waste disposal appears to have initiated something of a public outcry against using the sea as an international dustbin, Britain's methods of discharge from Windscale and Winfrith coming in for quite heavy criticism, if not directly, at least by implication. Why this should suddenly arise is not easy to see, as the system adopted has been discussed at length in the past at such gatherings as the Geneva conference, and although technical arguments have developed there has been no emotional outburst. Recent measurements indicating that the ocean deeps cannot be regarded as stagnant have raised new questions on the advisability of dumping high-activity material in ocean trenches but this is a different matter from the discharge of very low active liquors into seas where strong currents ensure rapid dilution.

The concentration of isotopes by marine life is not a new discovery and very extensive work on the N.W. coast of England has allowed a continuous check to be kept on the build-up of activity in fish and plant life. None of this work has indicated that dangerous levels are likely to be approached; rather has it served to prove the conservatism of the original specifications.

Popular analyses of the dangers of sea dumping tend to ignore the considerable activity natural in the sea mainly from potassium-40 but not negligibly from uranium in equilibrium with its many daughter products through the radium series. Even when this is appreciated it is too easy for countries with vast areas of useless land under their domain to plead that the activity should not be increased at all, but this is scarcely a realistic attitude. Also one cannot be confident that there are no political motives behind some of the " holier than thou " attitudes.

Nonetheless there is real concern in the world that inadequate control today may hazard the well-being of future generations; but it must be remembered that the establishing of activity levels in waste, and rules governing its disposal, do have an economic significance.

International agreement on these safety problems is of vital importance and to this end the airing of fears and uncertainties can only do good. Let us hope that in the end techniques and activity levels are based on valid experimentation and a realistic philosophy, and that emotional considerations will have a steadily decreasing significance.

DIGEST...

Surveying Significant News

U.S.-U.S.S.R. Reciprocal Exchange Programme

Following Kruschev's visit to the U.S.A. last September and that of Professor Emelyanov, and Mr. McCone's tour of Russia, the U.S.A. and the U.S.S.R. have signed a memorandum which makes provision for the reciprocal exchange of unclassified information and for the exchange of scientific personnel for limited periods. The specific fields of research involved are controlled thermonuclear work, basic research in nuclear physics and high energy physics, and civilian power reactor technology. The feasibility of joint projects will be examined with the IAEA acting in an advisory capacity. The IAEA will receive information arising out of the exchange—but even so, this bilateral agreement will do little to enhance its authority.

Authority Membership to be Increased

The Bill providing for an increase in the Atomic Energy Authority membership was given its second reading on November 18. In the Atomic Energy Authority Act, 1954, it was laid down that the Authority should comprise under the chairman, 10 members maximum, and these posts are at present filled by four permanent and six temporary members. In view of the division of the Industrial group and the desire to retain Sir John Cockcroft as a part-time member, there is a requirement for at least two new places, the designate member for Production being Sir Leonard Owen. Envisaging a similar situation arising in the future, the Government proposes that the maximum number should now be increased to 15. The same bill also makes provision for the AEA to admit employees of NIRNS into its superannuation scheme: this will simplify the interchange of staff between the two organizations.

U.K. AEA Ship Propulsion Evaluation

Once again the AEA has chosen a conference overseas to make known its opinions on a nationally important subject. At the recent ship conference in Hamburg (pages 14-18) the AEA came down firmly in favour of organic moderation as the system holding the greatest potential for merchant marine development. This opinion will no doubt be incorporated in the Galbraith Committee report at present being considered by the Government. The United States, on the other hand, has persevered with its thesis that the system with the most promise in the very long term is the closed-cycle, helium-cooled, gas turbine system, beryllia now being recommended as moderator. In next month's issue we shall be giving the OMR extensive coverage.

Work at Hunterston Still Delayed

An examination of the Hunterston site gives no clue to the reasons for the labour disputes that have so impeded the work on this reactor project. In the boiler shop, manufacturing conditions would appear to be ideal and much nearer factory conditions than normally encountered on site. Even in the temporary structures erected over the pressure vessel sections little fault can be found with working conditions. The civil engineering has gone ahead rapidly and is now waiting on the fabricators, although some re-orientation of the programme is allowing civil work to continue ahead of the schedule originally planned. It is to be hoped that when agreement is reached a lasting contract will emerge and that the very high-quality work that has been proved possible on the site will become normal practice.

Finland Requests Enriched Uranium from the IAEA

Finland has asked the IAEA to supply 2.6 kg of 20% enriched U^{235} to fuel the TRIGA Mk. II reactor which she is purchasing and also 3 kg of 10% enrichment for a critical assembly. In addition, assistance in fabricating the material has also been requested. The IAEA can make no direct quote and has asked the U.S.S.R., the U.S.A. and the U.K. for terms. In May last year the U.S.A. agreed to make available 5,000 kg of U^{235} together with equivalents of other offers; the U.S.S.R. promised 50 kg and the U.K. 20 kg. At the same time the U.S. agreed that charges would not be higher than those applying to domestic consumers: the U.K. has stipulated that British prices would be no less favourable than the ones offered to other foreign buyers.

German Atomic Energy Act

The Bundestag has passed the Atomic Energy Act. The law will provide for the private ownership of fissile material and general private exploitation of nuclear energy, although a system of licensing will be instituted. The regulations require third-party insurance up to a certain limiting figure, to be determined on the merits of each case. Over and above this, to a maximum of £42½ million, the Government will provide guarantees.

The Dragon Project Thrusts Ahead

Confounding the doubts of those who are sceptical of the practicability of organizing a reactor design project on an international footing, the Dragon project at Winfrith is going ahead rapidly. Not all the problems of international tendering have been faced, but the present "European" atmosphere is making light of these difficulties. Designs for the 10 MW experiment will be frozen shortly and will follow closely the preliminary designs drawn up by the AEA.

U.K. Enriched Uranium Prices

What significance should be placed on the figure, quoted in the AEA's paper to the German Ship Conference, for the price of enriched uranium? A starting price of £8,000/kg for 93% enrichment is given but, presumably advisedly, propulsion costs are also calculated for a price of £5,000/kg. These correspond to $22.4 and $14/g respectively, the first figure being some 30% above the present American price and the second nearly 20% below. In view of past comments on the high cost of enriching in this country, even the 30% figure would seem unduly optimistic and it is difficult to see any basis for the second.

AIF Justifies Current U.S. Fuel Prices

An independent committee appointed by the Atomic Industrial Forum has confirmed that U.S. enriched fuel prices are not subsidized (except in terms of the 4% hire charge) and that present capacity will support 40,000 MW of enriched uranium reactors. Should military demand fall, part capacity operation should not influence price. A new plant for 4 C_0 material using power at 4 mill/kWh, and at a capital charge of 14% would give similar priced output. If power were fed from nuclear plants, this would raise the price to less than 10% above current figures.

Expanding Use of Impregnated Graphite

Hawker-Siddeley are installing one set of three furnaces at their Langley Laboratories, and are making provision for a further set as demand increases, for the impregnation of graphite by the furfuryl alcohol process developed by RAE Farnborough. Two 8-cwt furnaces operating on a five-day cycle are used in conjunction with a 1-ton graphitization furnace. The set-up is believed to be the most advanced of its kind in the world. In addition to preparations for the HTGC programme, and experiments on sleeving for the EDF2 reactor, an increasing demand for impregnation is arising from manufacturers of heat exchangers, electrodes, crucibles, etc.

Meyrin Proton Synchrotron Becomes Operational

On November 24 the 200 meter diameter proton synchrotron at the European CERN Research Centre at Meyrin reached its design energy of 24,000 MeV. Twelve nations are co-operating in this venture and the successful production of a stable beam is the result of six years' design and construction. The accelerator—which called for engineering skill (both mechanical and civil) of the highest quality—is based on a principle not previously tried and this early success reflects great credit on the team responsible. The beam extraction systems must now be commissioned to bring the machine into full operation.

Report on Beryllium Development

In this issue (pages 31 and 32) we review some of the work that is being undertaken in this country on the development of beryllium as a canning material. Recent statements have suggested that the first charge of AGR would be canned entirely in stainless steel and that confidence in beryllium was low. These would appear to be unfounded. The comparative evaluation of stainless steel versus beryllium canning for AGR is a continuing process and the proportion of the first charge that will use stainless steel will not be finally decided until nearer the time for loading.

Reactor Briefs

Third reactor at Chapelcross on full load on December 7 . . . U.S. AEC's Fast Source Reactor at NRTS, Idaho Falls, critical on October 29 . . . A.I. 50kW solution reactor, at the Enrico Fermi Nuclear Study Centre, Milan, critical on November 30.

Commissioning DFR

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A number of unusual problems delayed the approach to criticality of Britain's first fast breeder. This article describes some of the major difficulties and the way in which they were overcome by the staff at Dounreay. The major design details of the reactor appear in *Nuclear Engineering*, 1957, June, No. 15.

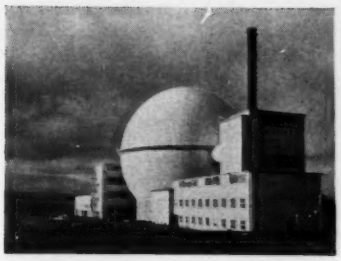

Fig. 1.—DFR with the element storage, control and administration buildings in the foreground.

AS briefly mentioned last month (p. 466, December issue) the Fast Breeder Reactor at Dounreay went critical for the first time on November 14. The DFR is designed as an experimental breeder reactor which can utilize uranium or plutonium as fuel in the core. The designed power output from the reactor core is 60 MW(t), using a sodium-potassium liquid-metal alloy as a coolant.

Early in December, 1958, the fast reactor was handed over from the Construction Group, who had built the reactor, to the Operations Group. Operations Group had at that time prepared a programme of work covering the period between handover and the reactor reaching criticality. This programme extended over 26 weeks, but in fact it was 50 weeks before criticality was achieved. The commissioning programme was divided into four main phases:—

1. Testing of flasks and removal equipment.
2. Charging natural uranium elements into the reactor.
3. Filling the coolant circuits with liquid metal.
4. Critical assembly.

Testing of Flasks and Removal Equipment

A stringent testing programme was laid down for all equipment used to transfer components in and out of the primary liquid-metal coolant circuit. The first part of this programme consisted of testing "in air," and the second part in liquid metal. It was not only necessary to ensure that the equipment functioned as designed, but it was essential that in normal operation it completely excluded air from coming into contact with the liquid-metal coolant.

Control-rod mechanism flasks, control-rod carrier flasks, the liquid-metal level indicator flask and the charge plug flask were all tested in this way. Each flask is essentially a shielded steel cylinder, 2 to 3 ft in diameter, 10 to 20 ft high and weighing several tons. The flasks contain a grab that can be lowered into the reactor, provision being made for operating the grab in its down position, while a valve on the lower end of the flask serves as an air-tight seal (Fig. 3).

Difficulties arose early in the testing in air and these led to some modifications being made. The main problems were:—(a) Although top and bottom limit indication was provided for the grab, more accurate positional indication was found necessary, since it often had to operate within a range of $\pm\frac{1}{4}$ in. A tachometer on the grab lowering mechanism provided this indication. (b) The motorized drive associated with the grab lowering mechanism was insensitive to jamming of the grab or of the lifted component when it was being removed from the reactor. The effort applied by the motor either aggravated the jamming or broke the lifting cable. This in itself was serious enough, but if this should happen when removing a component from liquid metal a major problem would be presented of carrying out remedial work without air getting into contact with the liquid metal. All motorized drives were finally replaced by hand drives and shear pins were used to limit the load that could be applied when raising equipment. (c) Throughout the tests it became obvious that the ability to see into the flask would not only save time, but it would make the operation safer. On several occasions, equipment jammed as it was being lowered, the cable slackened, and wound off the drum. The sudden freeing of the jam not only led to excessive load on the cable, but the dropping component could also have caused serious damage to the reactor. Small windows were therefore provided on the

Fig. 2.—(Left) Scene inside the reactor sphere.

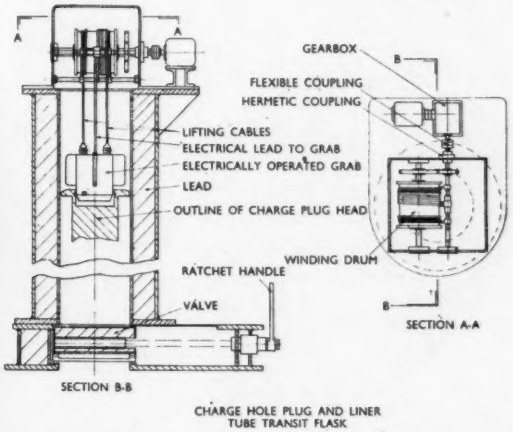

Fig. 3.—(Above) A typical transit flask.

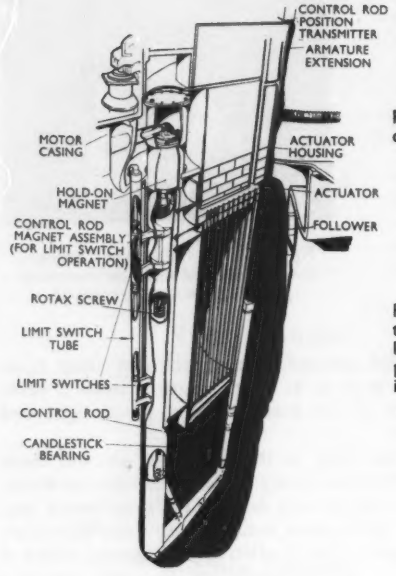

Fig. 4.—(Left) View of single control rod mechanism.

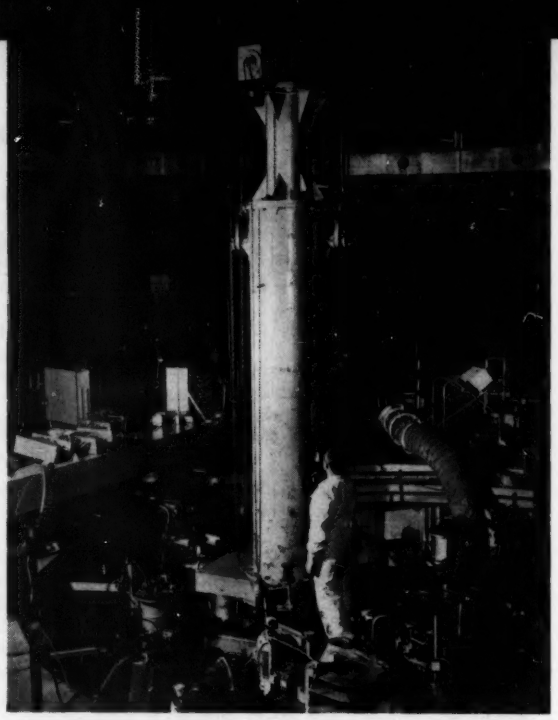

Fig. 5.—(Right) Control rod mechanism being lowered into position. The chain is for hand winding the grab.

flasks, special shielding covers being provided for use when a radiation hazard existed.

The major work in this testing period was the removal and replacement of all 12 control rod mechanisms. Although mechanically identical each control rod required individual setting in the removal flasks. The first stage of the operation consisted of removing the magnetic clutch assembly through which the control rods were driven. The L-shaped control rod mechanism (Fig. 4) was then raised at the same time as the horizontal arm of the L was being lowered to enable the whole mechanism to be raised vertically into a shielded flask (Fig. 5). Replacement was the reverse of this procedure, a new copper joint ring being required beneath the clutch assembly.

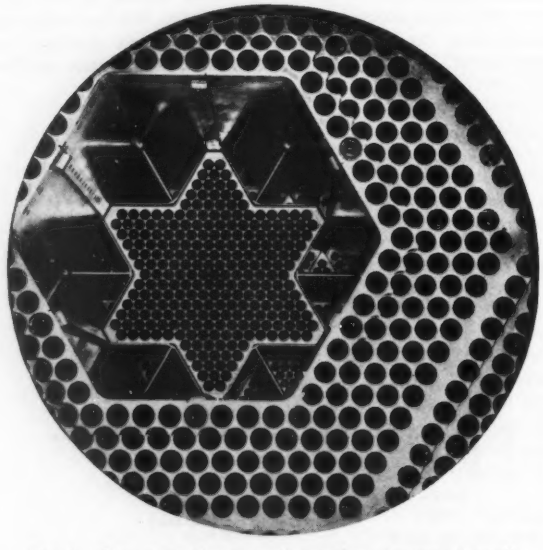

Fig. 6.—Plan view of core and breeder element channels. The tops of the triangular-shaped control rod carriers can be seen at the bottom of their guide tubes.

It was expected that each control rod removal and replacement would take 24 hours, but the trials revealed the need for numerous minor alterations to the removal equipment to allow it to be installed and to function correctly in each of the 12 positions. These modifications, although minor, occasionally extend the time taken for removal and replacement of one rod up to 3 or 4 days. At the end of this period of testing in air, the maintenance engineers were fully conversant with the equipment and had confidence in their ability to remove any component from the primary coolant circuit should it be necessary.

The testing of the removal equipment after liquid metal had been loaded into the circuit did not present any further major problems. Because of the complexity of the tests, and the thoroughness with which they had been done in air, the tests in liquid metal were not as extensive, and only one of the 12 control rods, for example, was removed and replaced. The major difference in technique at this stage was that all flasks had to be purged free of oxygen prior to use. Oxygen free nitrogen was used for purging, the flasks being repeatedly pressurized to 5 p.s.i.g. and vented until the oxygen content was below 100 ppm.

Charging Natural Uranium Elements

The Fast Reactor has 2,239 channels into which elements can be inserted, 1,872 of these channels being for breeder elements, and 367 channels being for core elements (Fig. 6). Prior to the critical assembly 2,100 of these channels were charged with natural uranium fuel elements, most of this charging being done in air; about 150 elements were charged after liquid metal had been put into the reactor to test the charge machine (Fig. 7). This machine weighs 25 tons and stands 30 ft high, and handles one core element (weight, 7 lb) or one breeder element (weight, 80 lb) at a time.

The element charging sequence is briefly as follows: New elements are brought into the sphere and charged by hand into the canning station magazine. Each element is rotated from the horizontal to the vertical position in the canning station and is then raised into the charge machine. Valves on the charge machine and canning station are closed and the charge machine with the element inside is transferred to the reactor top where the element is lowered into the reactor.

Irradiated elements are removed from the reactor into

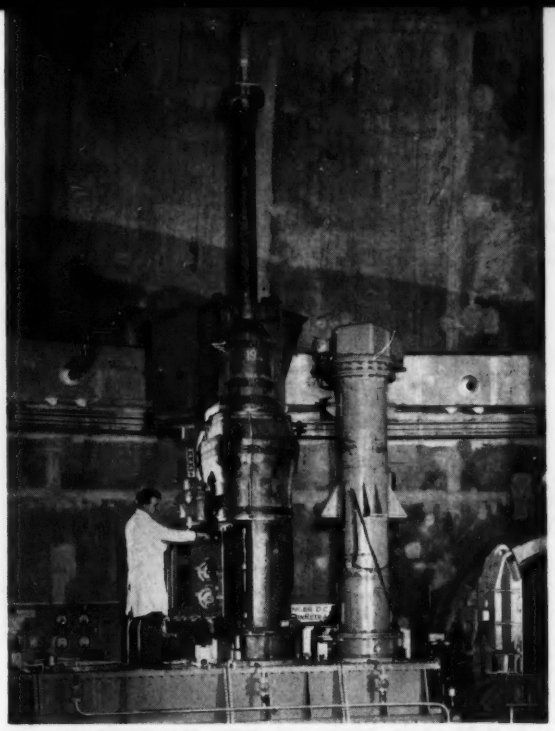

Fig. 7.—(Left) Element charge machine and a breeder element transit flask above the canning station.

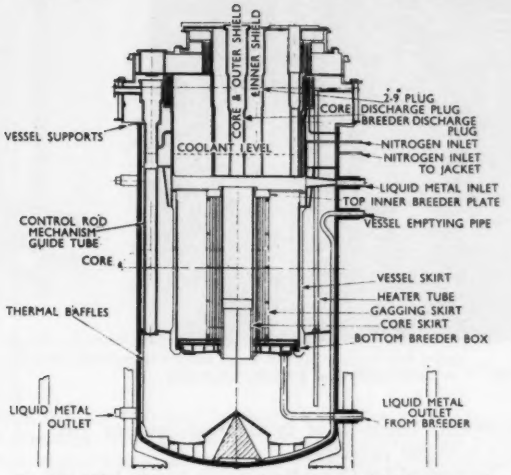

Fig. 9.—(Above) Reactor vessel showing guide tube through which the control rod mechanisms were removed.

the charge machine and are then transferred to the canning station. In the canning station the elements are sealed in lead-lined steel cans before being transferred in a shielded flask to the cooling pond. All valves through which the elements are passed are electrically interlocked to prevent the valves being closed on the element or to prevent the valves being left open, thus allowing air to come into contact with the liquid metal.

Three main problems were presented: (a) To check the correct functioning of the element handling equipment, charge machine, canning station, transit flasks, etc. (b) To position the element charging hole accurately over the required element channel, and (c) To locate the end of the charge machine grab into the selected element in the reactor. The correct functioning of the element handling equipment was checked by repeated dummy runs with the elements through complete sequences of operation.

The reactor vessel is a stainless steel pot 10 ft 6 in. diameter, all the 2,239 core and breeder elements being contained in this pot. A large cylindrical plug known as the outer rotating shield fits into the top of the reactor vessel and a smaller plug, the inner rotating shield, fits eccentrically inside the large plug (Fig. 10). All elements are charged into the reactor through one of two 7-in. diameter holes in the inner rotating shield. Both the inner and outer rotating shields can be rotated independently so that the 7-in. charging hole lines up with the selected element channel. The angular position of the two shields was checked and rechecked for each one of the 2,239 element channels using an optical sighting device, a graduated scale around the periphery of each shield being calibrated for each individual channel.

The core elements are on a pitch of 0.9 in., the breeder elements on a pitch of 1.63 in. Core elements had to be lowered a distance of 15 ft into the selected channel. To remove core elements the charge machine grab had to be lowered a distance of 15 ft into a hole 0.32 in. diameter in the top of the element. In order to obtain such precise alignment the charge machine had to be set up extremely accurately and extensive trials were carried out on a model of the reactor core before the charge machine was used on the reactor.

Experience with the element charging sequence showed that it would take about one hour to charge each element. In order to save time most of the breeder element charging was therefore done with a simple hand-loading device (Fig. 11).

Filling the Coolant Circuits with Liquid Metal

A major problem in the commissioning of the fast reactor was undoubtedly the filling of the coolant circuits with liquid metal. Not only were many technical problems presented, but there was an overriding managerial problem in preventing accidents.

A total of 119 tons of liquid metal was charged into the circuits, 51 tons into the primary circuit and 68 tons divided among the 12 secondary circuits.

The liquid metal charged into the circuits was an alloy of sodium and potassium (NaK) containing 72% sodium by weight. The liquid metals supplied were of four different compositions, pure sodium, 40/60% NaK, 50/50% NaK and "eutectic" 22/78% NaK. (Sodium figures quoted first.) The sodium was supplied in 295 drums (4 cwt each) and the NaK in 1,200 drums (1 cwt each). The

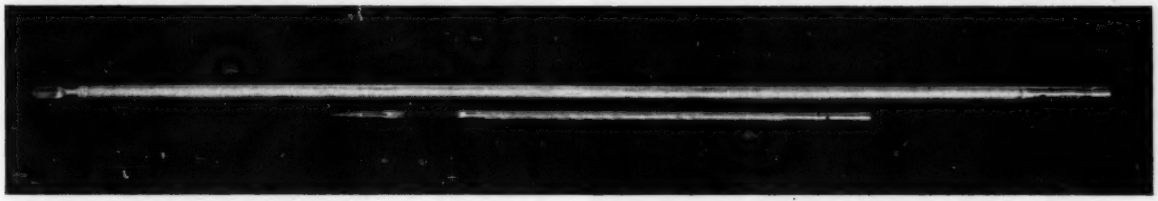

Fig. 8.—Breeder and core elements. Holes near the top and flutes at the bottom assist coolant flow.

Fig. 11.—Hand loading of breeder elements.

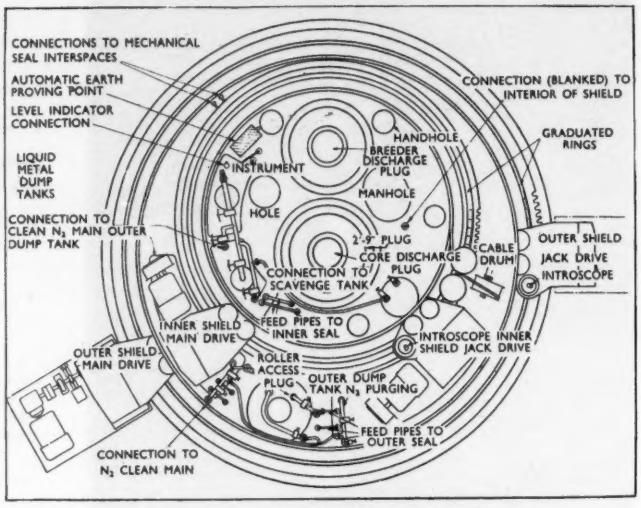

Fig. 10.—Plan of rotating shields.

mechanical handling of these drums was in itself quite a major operation.

The method for filling the circuits was to heat the metal containers electrically, and transfer the NaK separately under nitrogen pressure, and the sodium by gravity in a predetermined weight ratio into a discharge vessel (Fig. 13). The alloy was then transferred from the discharge vessel through coarse and fine filters into eight dump tanks capable of holding the complete primary charge and three (of the 12) secondary circuit charges. From the dump tanks the liquid metal was blown, using nitrogen pressure, into the required circuit.

All the handling of liquid-metal containers was carried out in the liquid-metal charge station outside the sphere. The design of the charge station was influenced by the fact that the operation was a "one off" job; hence the minimum amount of instrumentation was installed. Also, the liquid metal was expected to be reasonably free from contaminants, and this led to a somewhat inflexible plant from a maintenance aspect.

Much of the NaK alloy had been standing for 2 to 3 years and when it came to be used it was found that the liquid (50/50 NaK has a melting point of 12°C) in the drums had formed solid deposits which could not be penetrated by vigorous probing with a ¼-in. rod. Even when heated to 120°C solid residues remained in many of the drums. These residues were responsible for numerous blockages in pipework, valves and filters in the first two months of operation of the charge station, and continuous modification was needed to improve the flow.

Some of the changes made were:—(i) New pipework with right angle bends and plugs was made to allow blockages to be cleared using long rods. (ii) "Straight through" valves were fitted in place of valves with a tortuous flow path, again to permit pipes to be "rodded." (iii) Pressure gauges were fitted across the filters. (iv) Removable pipe sections were made to allow work to continue while blockages were cleared. (v) All tools used were preheated in a furnace. (vi) Flexible pipe sections were made to allow work to continue while blockages were cleared. (vii) Both coarse and fine filters were replaced.

Gradually the problems were overcome and an acceptable charging rate was achieved. These delays did not in fact influence the main reactor programme, since the liquid metal was available for charging into the reactor before the reactor was ready to receive it. The transfer of liquid metal into the primary and secondary circuits proceeded smoothly (Fig. 14) and the complete primary charge of 51 tons was transferred from the dump tanks into the reactor in less than 24 hours. Each secondary circuit, capacity 5½ tons, was charged in about 16 hours.

Throughout the whole liquid metal charging operation only a few minor accidents occurred to personnel. These

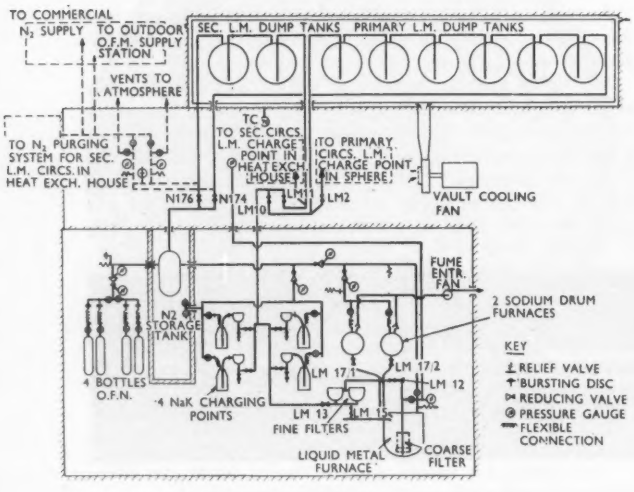

Fig. 12.—(Left) Line diagram of the original liquid metal station.

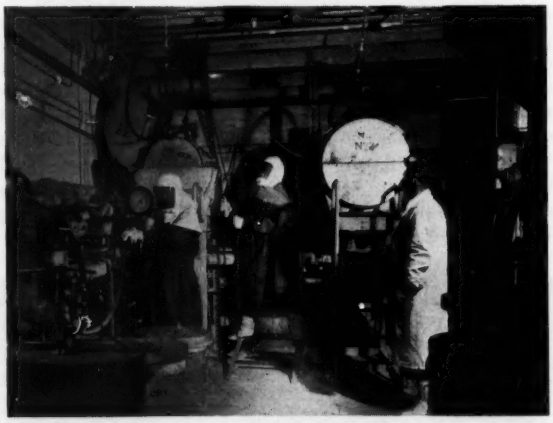

Fig. 13.—(Above) Liquid metal charge station. At rear: lowering a sodium drum in a heating muff.

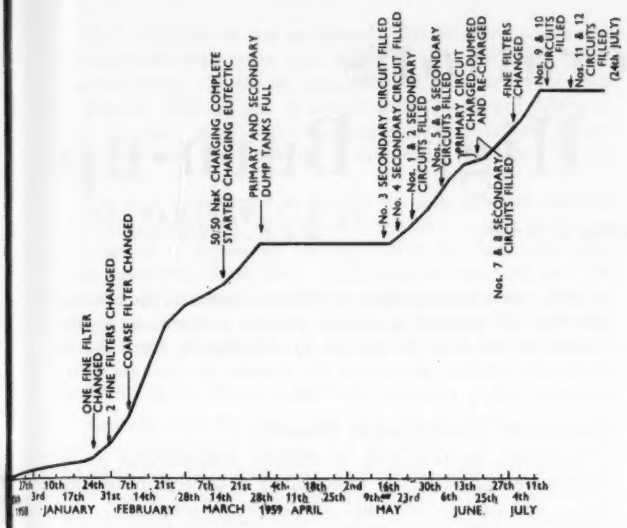
ONE FINE FILTER CHANGED
2 FINE FILTERS CHANGED
COARSE FILTER CHANGED
50:50 NaK CHARGING COMPLETE
STARTED CHARGING EUTECTIC
PRIMARY AND SECONDARY DUMP TANKS FULL
No. 3 SECONDARY CIRCUIT FILLED
No. 4 SECONDARY CIRCUIT FILLED
Nos. 1 & 2 SECONDARY CIRCUITS FILLED
Nos. 5 & 6 SECONDARY CIRCUITS FILLED
PRIMARY CIRCUIT CHARGED, DUMPED AND RE-CHARGED
FINE FILTERS CHANGED
Nos. 7 & 8 SECONDARY CIRCUITS FILLED
Nos. 9 & 10 CIRCUITS FILLED
Nos. 11 & 12 CIRCUITS FILLED (24th JULY)
17th 10th 24th 7th 21st 7th 21st 4th 18th 2nd 16th 30th 13th 27th 11th
3rd 17th 31st 14th 28th 14th 28th 11th 25th 9th 23rd 6th 25th 4th
1958 JANUARY FEBRUARY MARCH 1959 APRIL MAY JUNE JULY

Fig. 14.—Rate of charging liquid metal into the dump tanks.

resulted in small burns to the skin, caused mainly by accidental contact with NaK contaminated protective clothing and equipment.

Initial Operation of the Liquid Metal Circuits

One of the fundamental problems arising from the use of NaK as a coolant is that solid sodium oxide (Na_2O) forms immediately air comes into contact with the NaK and solution of this oxide confers strong corrosion properties upon the coolant.

After charging the circuits the liquid metal was circulated through the cold traps to remove sodium oxide from the system. When attempts were made to raise the control rods, however, it was found that they could not be moved. Examination revealed that the free liquid metal surface above the control rod mechanism was heavily covered in free oxide (Fig. 15). As operation of the control rod causes the moving parts of the mechanism to pass through the surface, it was deduced that the oxide had produced the mechanism seizure. The freeing of the control rods and the cleaning up of the surfaces caused a major

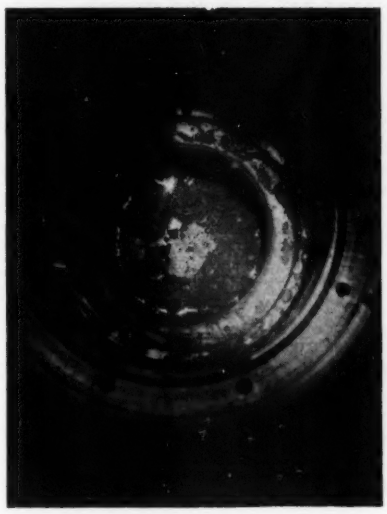

Fig. 15.—(Left) Control rod tube prior to cleaning oxide-contaminated liquid metal surface.

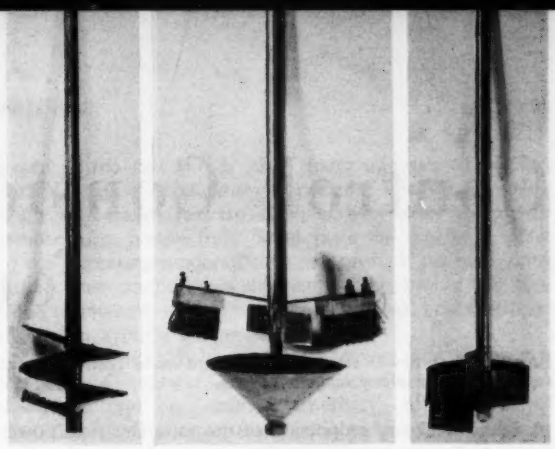

Fig. 16.—Special purpose gadgets made for cleaning up liquid metal surfaces and joint faces of the control rod tubes.

setback of over two months in the reactor programme. It was found possible, by the use of rapidly improvised tools, to free eight rods in position, but four had to be removed completely from the reactor, stripped, decontaminated and replaced. This provided the maintenance engineers with an opportunity to put into practice the techniques established during the in air tests. After all the rods had been freed a further period of cold trapping was carried out.

It should be mentioned that the jamming of the rods in no way affects their ability to shut down the reactor in the event of an automatic trip signal arising in the safety circuits. It only prevents their being raised or lowered at the slow speeds required for normal control.

Critical Assembly

The approach to criticality was effected by interchanging gradually the natural uranium elements in the core with enriched fuel elements containing 45.5% U^{235}. The elements in the 12 control rods and the outer edge of the core were interchanged first, the remaining elements being interchanged in stages working from the centre of the core outwards. As no radiation hazard was involved a simple hand charge machine was fabricated in order to save time during the critical assembly.

Previous calculations had indicated that 235 of the 367 core channels would contain enriched elements when criticality was reached with all the control rods in. (Control of the fast reactor is effected by moving fuel elements in or out of the core and not by the use of neutron absorbers.) The actual number required was 234.

No special difficulties were encountered during the loading of the critical assembly which started on October 28. The reactor went critical on November 14. At a power level of 25 watts the experimental programme began.

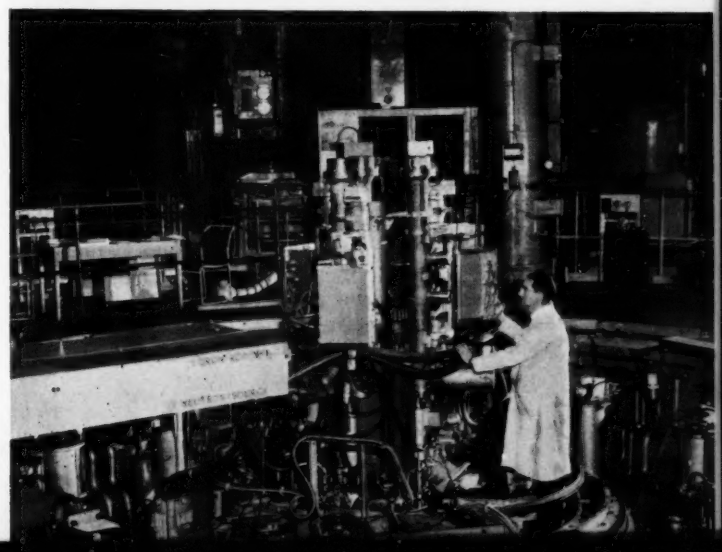

Fig. 17.—(Right) Equipment above the reactor vessel in final preparation of the critical assembly.

Control Considerations for High Burn-up

By R. I. VAUGHAN, M.A.
(R. & D. Group, U.K. AEA)

Future nuclear power stations will require more precise control facilities to permit steady operation over a range of powers.

As an increasing proportion of the total electrical power is to be generated in nuclear power stations, the need will arise for at least some of these stations to be operated with reduced power outputs at certain times.[1] It is therefore desirable that the control systems of the nuclear stations should permit steady operation over a range of powers. Also, it may be required to regulate the frequency in the grid with nuclear power stations at times when these are taking up the bulk of the load.

Under normal operating conditions, the power output will be very nearly directly proportional to the product of the rate of flow and of the temperature rise of the coolant gas through the reactor. For best efficiency, gas temperatures must be as high as possible, the upper level being limited by metallurgical considerations relating to the uranium fuel and the fuel element cans. The thermal neutron flux within the reactor core and the gas flow through each coolant channel will be so adjusted that the estimated peak can temperature is the same for all channels under full power conditions. The heat output from each channel will vary with distance from the core axis roughly as shown in Fig. 1 and to achieve uniformity in peak can temperature, the coolant flow rate will be the same in all channels in the flattened zone and lower in channels nearer the core periphery.

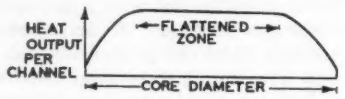

Fig. 1.—Power distribution across reactor core.

Requirements for Control

Control of the plant will be effected primarily by moving the neutron absorbing control rods in the reactor, by varying the flow rate of the coolant gas circulating through the reactor and the steam raising units and by varying the settings of the governor valves admitting steam to the turbines. It will usually be required that the plant should provide a demanded electrical output with the steam pressures near certain fixed levels and with temperatures in the reactor core not exceeding certain permitted values. A possible method of control is to

(i) regulate each reactor by movement of the control rods so as to maintain constant the temperature of the coolant gas leaving the reactor,

(ii) adjust the coolant gas velocity and steam flow rates so that the required power output is achieved with the desired steam pressures.

There is clearly the possibility of a strong interaction between the regulation of coolant temperature with the control rods and the adjustment of gas flow rate by varying the speed of the circulators. However, the thermal capacities and heat transfer conditions in the steam raising units are such that some minutes will generally elapse before a change in the temperature of the gas entering the steam raising units is reflected in a comparable change in the temperature of the gas leaving the units. Consequently, an understanding of the problems arising from the need to control a power reactor containing highly irradiated fuel may be gained by considering the case in which the coolant gas enters the reactor at constant temperature with a constant flow rate.

Temperature Coefficients of Reactivity

Variations in fuel and moderator temperatures in a reactor induce reactivity changes in each region of the core. The *fuel* temperature coefficient of reactivity with natural uranium fuel is negative, the principal factor being the phenomenon of Doppler broadening. An increase in fuel temperature leads to an increase in the absorption by U^{238} of neutrons which have not been fully slowed down to thermal energies in the moderator.[2] The net fuel temperature coefficient will typically be about $-2\times10^{-5}\ \delta k/°C$.

Thermal expansions have negligible effect on reactivity in a gas-cooled graphite-moderated reactor since dimensional changes are small and the change in the number of atoms of the carbon dioxide coolant in the core has an insignificant effect on the chain reaction.

With only natural uranium in the fuel elements, the *moderator* temperature coefficient of reactivity is negative. This is primarily because:—

(i) An increase in moderator temperature leads to higher velocities of the thermalized neutrons.

(ii) The ratios of the fission cross-section of the U^{235} atoms to the absorption cross-sections of the other elements in the core (especially U^{238}) decrease with increasing neutron velocity.[2]

Resonance absorption leading to fission occurs in Pu^{239} with neutron energies of about 0.3 eV which is within the thermal spectrum. Consequently, the increase in the proportion of thermal neutrons at higher energies due to an increase of moderator temperature causes an increase in k_∞ if there is sufficient Pu^{239} in the fuel elements.

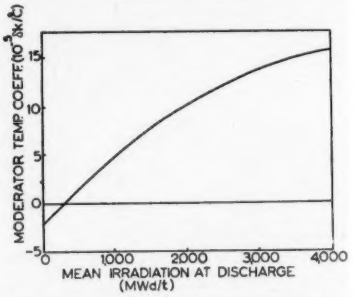

Fig. 2.—Variation in temperature coefficient with fuel irradiation.

In a power reactor an average of about 3,000 MWd of energy may be extracted from each tonne of natural uranium fuel.[3] If 3,000 MWd/t is obtained from the fuel before discharge, the quantity of Pu^{239} which will be formed by neutron absorption in U^{238} may lead to a positive moderator temperature coefficient of reactivity of about $15\times10^{-5}\ \delta k/°C$.

The variation of the moderator temperature coefficient of reactivity with mean fuel irradiation at discharge, for a typical power reactor at operating temperatures is shown in Fig. 2. The values of temperature coefficient relate to the changes in k_{eff} (the effective multiplication factor) corresponding to uniform temperature changes in the moderator.

The fuel is assumed to remain in each channel until its average irradiation reaches the specified mean value of irradiation at discharge; the channel is then unloaded and recharged with fresh fuel. It is further assumed that the number of channels which have undergone a mean irradiation of between I and $I+\Delta I$ is independent of I when I lies between 0 and the mean irradiation at discharge.

Stability of the Reactor Power

Suppose that the flow rate and the temperature of the coolant entering a reactor are constant. If power is to be changed from one level to another, then the temperature changes within the core have a net effect on reactivity which must be counteracted by control rod movement. (Strictly the influence of changes in xenon^{135} concentrations arises here but this is discussed later.) If the net reactivity change from temperature effects is of opposite sign to the power change, then restoring the control rods to their original positions will cause the reactor power to return to its previous level; stability of the power output is not dependent on suitable control action.

If, however, the reactivity change from temperature effects is of the same sign as the power change then the compensating reactivity required from the control rods to keep equilibrium at the new power must be of opposite sign to the power change. This means that moving the control rods to their original positions will result in a reactivity swing tending to increase the magnitude of the initial power change. Evidently a condition of instability exists if no stabilizing control action is taken.

Following a sudden small increase in reactivity, power will increase rapidly until, after several seconds, the negative reactivity introduced by the rise in fuel temperatures almost exactly compensates for the initial reactivity disturbance. Were reactivity independent of moderator temperature, the power of the reactor would change little more a minute or so after the disturbance, the moderator temperatures approaching the equilibrium value appropriate to the new power after many minutes. However, with a positive moderator temperature coefficient, power will rise at such a rate that the reactivity effect of the fuel temperatures nearly fully counteracts the reactivity effect of the increasing moderator temperatures. If the moderator temperature coefficient is sufficiently high, power will continue to increase so that, eventually, control action will be needed to avoid a dangerous condition.

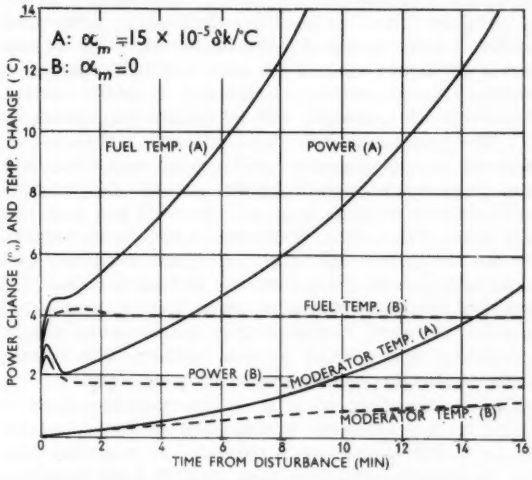

Fig. 3.—Transients following step in reactivity of 10×10^{-5} δk.

In Fig. 3 suitably weighted mean fuel and moderator temperature changes are shown together with power deviations for a sudden reactivity disturbance of $10 \times 10^{-5}\ \delta k$. One set of curves relates to a typical reactor with a moderator temperature coefficient of $\alpha_m = 15 \times 10^{-5}\ \delta k/°C$, the other set to a reactor with zero moderator temperature coefficient. Disturbances of order $10 \times 10^{-5}\ \delta k$ could arise in, for example, the on-load changing of fuel elements but usually the reactivity changes would occur over many seconds. The rate of increase in power in Fig. 3 would give plenty of time for corrective control action.

The most significant parameters determining the uncontrolled variation in total power a few minutes after a reactivity disturbance are:—

(i) the fuel and moderator temperature coefficients of reactivity,

(ii) the changes in fuel and moderator temperatures for a given power change,

(iii) the time lag between changes in power and changes in moderator temperatures. In general this will be some minutes; the lag between power and fuel temperature changes will be a fraction of a minute under full power conditions.

Influence of Xenon Absorption

During steady operation at full power, between 1% and 2% in reactivity will be taken up by xenon^{135} in the fuel elements. The immediate effect of an increase in neutron flux (i.e., in power) is an increase in the rate of destruction of xenon^{135} through neutron absorption which in turn tends to increase reactivity; the cross-section for neutrons of 2,200 m/sec velocity is 3×10^6 barns. The change in the rate of formation of xenon^{135} resulting from the increased rate of formation of iodine^{135} does not become appreciable for a time of the order of an hour owing to the 6.7-hour half life of iodine^{135}. Thus the immediate effect on power of changes in xenon^{135} concentrations following a power increase is destabilizing and a similar argument shows xenon^{135} to have a destabilizing effect following a power drop.

Several hours after a power increase, if the power deviation has not become too rapid, the greater rate of formation of xenon^{135} due to the increased concentration of iodine^{135} begins to outweigh the rate of destruction due to neutron absorption. This results in a tendency for power to be restored to its initial level. Thus it may be appreciated that under certain conditions oscillations can arise, the amplitude of the oscillations building up or decaying depending on the neutron flux levels prevailing in the core and on the reactivity effects of temperature changes.[4] Such oscillations have a period of roughly one day so that they would be suppressed easily by suitable control rod movements made a few times a day. Fig. 4 shows deviations in power and in the reactivity effect of the xenon^{135} concentration in a reactor where conditions for power oscillations exist.

If a reactor is in a condition whereby total power is inherently unstable by virtue of temperature effects alone, then xenon^{135} merely has an aggravating effect and

uncontrolled power excursions take the form of steadily increasing non-oscillatory deviations. With a positive moderator temperature coefficient as high as 15×10^{-5} $\delta k/°C$, xenon^{135} only slightly affects the rate of increase of uncontrolled power deviations.

Suppose that a fuel charge consisting initially of natural uranium were left undisturbed in a Calder reactor so as to undergo steadily increasing irradiation. As irradiation proceeded, the moderator temperature coefficient would increase from negative values to positive values and the forms of the responses of power output to small reactivity disturbances would change. If not more than a few per cent. of the steady power level, the uncontrolled power deviation following a disturbance may be expressed in the form:—

$$\delta P = a_o + \sum_r a_r \exp(t/\tau_r) \cos \omega_r (t-t_r)$$

where δP is the deviation in power at time t, and the a_o, a_r, τ_r, ω_r, and t_r are constants depending on the disturbance.

With a moderator temperature coefficient less than some critical value all the τ_r are negative, signifying that the power deviation subsides to a constant value. A sufficient time after the disturbance the power deviation will approximate to:

$$a_o + a_m \exp(t/\tau_m) \cos \omega_m (t-t_m)$$

where τ_m is the τ_r of greatest magnitude.

With a moderator temperature coefficient exceeding a critical value, one or more of the τ_r become positive and the power deviation approaches the form:

$$a_n \exp(t/\tau_n) \cos \omega_n (t-t_n)$$

where τ_n is the smallest positive τ_r.

Fig. 5 shows the results of calculations relating to a Calder reactor. The negative time constant of largest magnitude or the positive time constant of smallest magnitude is given together with the corresponding period where the power deviations are oscillatory. For values of the moderator temperature coefficient of reactivity α_m up to about 3.7×10^{-5} $\delta k/°C$ uncontrolled power deviations tend to an oscillatory form with a period of roughly 1 to 1½ days. However, as α_m approaches 4.4×10^{-5} $\delta k/°C$ the period becomes increasingly long and, for a given small disturbance, the power deviation before the first turning point becomes larger. Fig. 5 indicates that when α_m passes the value of 4.4×10^{-5} $\delta k/°C$ power deviations cease to be oscillatory. There are then two positive τ_r and power deviations will tend to the form $a_n \exp(t/\tau_n)$ where τ_n is the smaller of these two time constants.

Stability of the Flux Shape

Within any region of a reactor core there may be more or less neutrons absorbed than are produced by fission, the net excess rate of production being proportional to $(k_\infty-1)\phi$ where ϕ is the neutron flux. Under steady conditions, this net excess or deficit is exactly counterbalanced by the net flow of neutrons into the region. If k_∞ changes uniformly throughout the core, then the neutron flux will grow or decrease without change of shape. However, if k_∞ changes by differing amounts (e.g., due to differing temperature changes and temperature coefficients between various regions), then there will also be changes in the shape of the flux distribution.

Suppose a reactor is in a condition where reactivity changes are caused only by control rod movements so that effects of temperature, etc., on reactivity are neglected. Suppose further, that the penetration of a partly inserted control rod is increased by a small amount and the core maintained in the critical condition by withdrawing other rods by small amounts elsewhere. The neutron flux will then be reduced in the neighbourhood of the rod with increased insertion and the net flow of neutrons into the region will be higher. If now the control rods are returned to their original positions, then a higher net flow of neutrons into the region with the depressed flux is maintained while the rods are in motion until the flux distribution is restored to its original form. Thus neutron leakage provides a stabilizing influence unless flux levels throughout the core are varying simultaneously in such a manner that the shape of the flux distribution is unchanging. Clearly, the higher the degree of buckling associated with an excursion in the flux distribution, the stronger will be the stabilizing effect of the leakage.

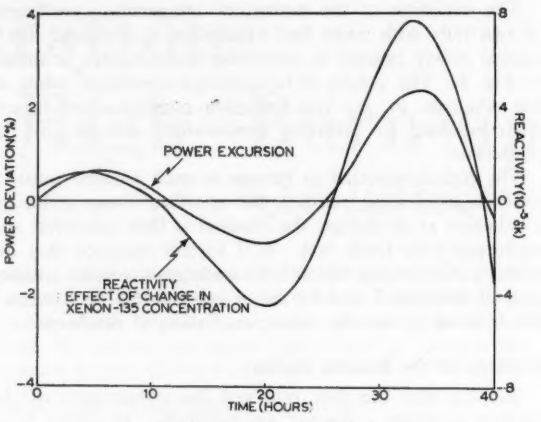

Fig. 4.—Long period power oscillations.

Consider now the more general case in which reactivity is influenced appreciably by variations in temperatures and xenon^{135} concentrations due to power changes. Any tendency for an excursion in flux shape to increase is:

(a) opposed by the effects of neutron leakage and of the negative fuel temperature coefficient of reactivity,

(b) increased by the effects of a positive moderator temperature coefficient and of xenon poisoning.

With a power producing reactor, conditions can be determined such that the factors (b) outweigh the factors (a) to the extent that unstable flux excursions of low buckling not entailing changes in total power could arise.[5] Suppose the reactor has a positive moderator temperature coefficient large enough for the flux shape to be unstable even if the total power of the reactor is held constant by suitable control action. Following a small reactivity disturbance, flux changes will take place throughout the core, being largest close to the disturbance. However, the shape of the flux deviation will change with time, large local irregularities smoothing out so that the excursion approaches an unstable form with growing flux deviations over most of the core. If the flux is sufficiently unstable, the flux excursion will, after an initial transient, grow exponentially with time. Where instability arises only from the combined effects of xenon and moderator temperature coefficient, conditions may arise in which the flux excursion in each part of the core oscillates with a period of about one day and ever-increasing amplitude.

The characteristic area to which buckling must be related in comparing the probabilities of spatial instabilities in different reactors is the neutron migration area. For the same neutron migration area, flux level and core temperature conditions, instabilities in flux shape (but not in total power) will arise with a lower positive moderator

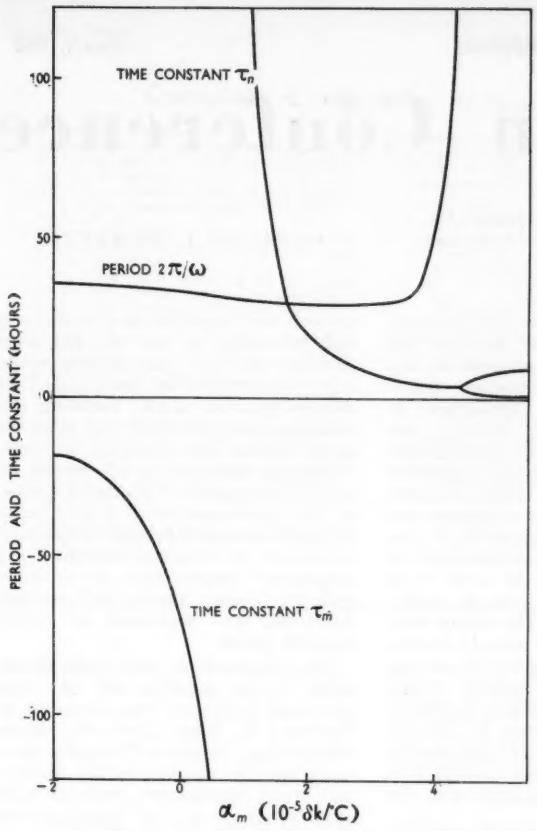

Fig. 5.—(Left) Time constants and periods in uncontrolled power excursions.

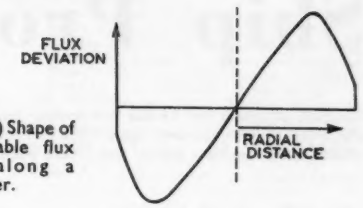

Fig. 6.—(Right) Shape of possible unstable flux excursion along a diameter.

temperature coefficient in a larger reactor than in a smaller one. This is because the least stable form of flux excursion not involving a change in total power will have less buckling in the larger core.

The stability of the radial flux distribution is also influenced by the steady state flux shape. For similar temperature conditions and levels of neutron flux, flux flattening will tend to reduce the moderator temperature coefficient at which instabilities arise in a reactor controlled only to give constant total power.

Instabilities in flux shape do not occur in any reactor now in operation in Britain but the power reactors now being built will, of course, be appreciably larger than even the Calder reactors.

With a large power reactor having a flattened flux over some 60% of the radius instability in flux shape might arise at full power at a moderator temperature coefficient of about $5\times10^{-5}\,\delta k/°C$ in the absence of suitable control action. (Without flux flattening, the critical moderator temperature coefficient would be some $9\times10^{-5}\,\delta k/°C$.) The shape of the flux excursion associated with this instability is approximately proportional to $F_1(r)\cos\theta$ where $F_1(r)$ is the function of distance from the core axis shown in Fig. 6 and θ is an azimuthal angle referred to some reference plane. The position of this plane depends on the disturbance initiating the flux perturbation.

To stabilize the flux distribution it is evidently necessary to constrain possible flux deviations to shapes with such large buckling that they are stable. The radial distributions of neutron flux may be stabilized by means of a number of groups of fine control rods, the rods in each group being automatically actuated by a control signal based on the measured power deviation over a certain region of the core. By so suppressing the flux deviations in several small regions, excursions of simple shape, such as that in Fig. 6, are prevented and buckling of the perturbations thereby increased. Clearly, the higher the moderator temperature coefficient, the greater will be the number of groups of fine rods required.

In practice, the deviation from a desired value in coolant exit temperature averaged over a number of coolant channels may form the basic error signal for each group of fine rods. It is likely that these groups will combine the functions of stabilizing total power and flux shape.

With the number of fine rod groups exceeding the minimum required to stabilize the flux shape, operation of the reactor at full power may be maintained even if one of the fine rod groups develops a fault. Thus if the electrical inter-dependence of the fine rod groups is reduced to a minimum, a reliable control system is possible with a very low probability of shut-down being necessary through the failure of automatic controllers. A suitable number to stabilize total power and the radial flux distribution in a typical large power reactor is about nine.

Axial Stability

The possibility of instabilities in flux shape primarily affecting the axial flux distribution must also be considered. Here one can conceive of a condition whereby flux levels rise in the upper half of the core and fall in the lower—or vice versa—with total power constant. Such instabilities could be suppressed by varying the distribution of control absorber between the top and bottom of the core. However, the core parameters and methods of operation of reactors now under construction will probably be such that axial flux instabilities will not arise.

With respect to possible later types of gas-cooled graphite-moderated reactors, enrichment of the fuel will lead to lower moderator temperature coefficients if the same quantity of heat is obtained from each tonne of uranium before discharge. This is because, with the lower ratio of U^{238} to U^{235} in the fuel, the concentration of Pu^{239} will be less for the same total number of fissions in each tonne of uranium. However, if more megawatt-days are to be obtained from each tonne of fuel in the later reactors, moderator temperature coefficients may arise as large as those possible in reactors fuelled with natural uranium. Any reductions in core size would be favourable to stability in flux shape but would not affect total power.

Instabilities in flux shape in the Shippingport pressurized water reactor have been reported.[6] These are essentially due to xenon poisoning effects since the reactor has a negative moderator temperature coefficient of reactivity. Consequently, only slowly varying flux excursions are entailed and their suppression by appropriate control action has presented no serious difficulty. The core of the Shippingport reactor is smaller than the cores in graphite-moderated power reactors but the neutron migration area is lower with water than with graphite.

REFERENCES

1. B.E.P.C., *Nuclear Engineering* 1958, **3**, 18, July, pp. 287-288.
2. Syrett, J. J., "Nuclear Reactor Theory." Nuclear Engineering Monographs, Temple Press, 1958.
3. U.K.AEA, Fifth Annual Report (1958-59), p. 12, H.M.S.O.
4. Schultz, M. A., "Control of Nuclear Reactors and Power Plants." McGraw-Hill Book Co. Inc., 1955.
5. Randall, D., and St. John, D. S., *Nucleonics* 1958, **16**, 3, March, p. 82.
6. *Nucleonics* 1958, **16**, 9, September, p. 72.

Ship Propulsion Conference

German proposal for 16,000 ton tanker powered by an OMR reactor of 12,000 s.h.p. discussed at international conference in Hamburg. AEA favour the organic moderated whilst the Americans prefer the future potential of a gas-cooled design.

By H. L. J. BURGESS

The Central Theme

THE second German Conference on Nuclear Ship Propulsion was held in Hamburg from November 25 to 28. Thirty-four papers were presented before an audience of some 750 delegates—nearly twice as many as attended the first conference two years ago. Fourteen nationalities were represented among the delegates.

To the delegate coming from a country with a stable and firmly established organizational structure of science and engineering in the nuclear field, the technical substance of the greater part of the papers appeared to add little to existing knowledge but the conference as a whole provided an excellent insight into the present state of affairs in Germany, where a young and fast growing nuclear community determined to be successful, professionally and commercially, is lacking the guidance, however, of a central authoritative professional organization to back and focus the scattered efforts initiated haphazardly all over the country.

The sponsor of the two conferences is the Institute for the Promotion of the Application of Nuclear Energy in Shipbuilding and Operation (Studiengesellschaft zur Foerderung der Kernenergieverwertung in Schiffbau und Schiffahrt e.V.), a non-profit-making body, founded in 1955 shortly after Germany was given permission to exploit nuclear energy for peaceful purposes. Members are shipbuilders, interested industrial companies, academic institutions, representatives of the Laender and Bundes Governments and individuals such as scientists specializing in a related subject. Total membership at present is 350 and funds invested up to date amount to DM.10,000,000, of which DM.3,000,000 have been subscribed by members and DM.7,000,000 contributed in the form of grants by the various governments.

In order to facilitate the practical exploitation of the ideas developed in, and the research results obtained by, the Studiengesellschaft, a subsidiary unit—the Company for the Application of Nuclear Energy in Ship Building and Operation (Gesellschaft fuer Kernenergieverwertung in Schiffbau und Schiffahrt m.b.H.)—was formed in 1956. The first major task of the latter company was the construction and operation of the 5-MW swimming-pool research reactor at Geesthacht, situated in the centre of a game reserve, 10 miles from the border with Eastern Germany. The reactor went critical for the first time some 12 months ago but, owing to complications arising from the absence of a national Atomic Law in Germany, permission to operate the reactor—at a maximum of 200 kW incidentally—was given only two months ago and thus the proposed scientific programme is still essentially in the planning stage.

Thus, admittedly, advances made in their own scientific work were not the reason for the organizers to call a second conference so early. The actual occasion was the decision to go ahead with the second task allocated to Kernenergieverwertung G.m.b.H., i.e., with the plan of building a nuclear ship. It is visualized that the ship could be ready for first trials in three years time, provided that the required finance were forthcoming in the very near future. The funds needed are estimated at DM.10-20 million. The project is being developed jointly with Interatom, a company owned 50/50 by North American Aviation (Atomics International) and Demag, a German concern. The initial design study is almost completed and a tanker built in 1937, the "Esso Bolivar" (16,000 dwt.), is earmarked for the purpose. It is proposed to replace the present propulsion machinery with an OMR reactor unit.

The various ramifications of this decision were bound to rouse controversy and, obviously, it was felt that some thinking aloud at this juncture might help substantially in establishing the plan in the minds of all. Therefore, this conference must be looked upon primarily as an internal event designed to inform a German audience on all aspects of, and the background to, the decision taken by the Studiengesellschaft. As a result the papers presented generally dwell more extensively on practical feasibility and commercial implications of technical principles already known, than on new discoveries and discussions of strictly scientific points.

The approach of the Studiengesellschaft to the problem and the spirit governing its actions were presented by Professor K. Illies (Chair of Marine Engineering, Technical University, Hanover, and the member of the Studiengesellschaft management responsible for engineering) in a brief speech—rather than lecture—during the first session of the conference:—

Initially, the aim of the Studiengesellschaft was to obtain recognition that nuclear marine propulsion is a subject in its own right requiring individual attention. Now, after "Lenin" and "Savannah" have taken to the water, this concept does not need to be argued.

The immediate task is to give the German engineer an opportunity of gaining first-hand experience in nuclear marine engineering. Economics, while certainly decisive in the end, should take second place at this stage. In an effort to shape a practical policy it is proposed to build the nuclear ship which is, however, to serve research purposes only (the term "for research only" was especially emphasized by Dr. Illies).

After long and careful investigations it was concluded that the advantages offered by the OMR-type of reactor, such as low pressures in the primary circuit, the use of mild—instead of austenitic—steels and the low magnitude of induced activity in the coolant make this type of reactor generally the most suitable for the project in hand. Consequently a contract was entered into with Interatom stipulating joint operations in the sense that the Studiengesellschaft supplies the know-how of general marine engineering and Interatom that of reactor design and construction. Accordingly, Interatom is responsible for

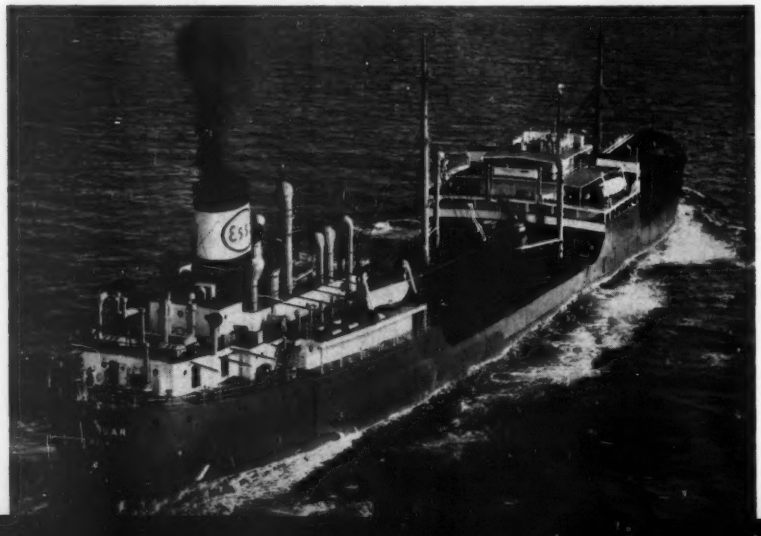

Fig. 1.—The "Esso Bolivar" (16,000 ton d.w.) has been earmarked as Germany's first nuclear ship.

Complete Conference Programme

General Studies and Economics
- "A Comparison of Nuclear Merchant Ship Propulsion Systems," by W. A. HEPBURN and D. H. SPECHT.
- "Application of Nuclear Energy to Ship Propulsion in the Federal Republic of Germany," by K. ILLIES.
- "A Comparative Study of Reactor Systems for Marine Propulsion," by H. P. KINSEY and H. W. BOWKER.
- "Economic and Social Aspects of the Utilization of Nuclear Energy," by G. FRIEDRICHS.
- "A Commercial Tanker with Reactor Drive," by J. P. HULSMAN.
- "Problems Related to Nuclear Propulsion Development in Norway," by J. WILHELMSEN, Jr.

The Organic Moderated Ship Reactor
- "Design Study of an Organic Moderated and Cooled Ship Reactor," by F. E. FARIS.
- "Planning Saturated-Steam Circuits in Organic Moderated Reactors," by H. DALDRUP.
- "Possible Reductions in Operating Costs During the Life of an Organic Moderated Reactor for Ship Propulsion," by I. D. NEILSON.
- "Organic Coolants for the OMR," by W. HAUBOLD.
- "A Study on the Arrangement of Tubular Fuel Elements in the OMR," by N. PAPMEHL and A. MARESKE.

Pressurized and Boiling Water Reactors
- "Progress Report 1959 NS. 'SAVANNAH,'" by R. W. DEUSTER.
- "Impressions of a Participant in the Work on the NS. 'SAVANNAH,'" by G. GROSSMANN.
- "The Boiling Water Reactor in Ship Propulsion," by H. J. BRUCHNER.
- "A Small Experimental Nuclear Ship," by M. YAMAGUCHI.
- "The Uses of the Siemens-Argonaut Reactor in Ship Reactor Experiments," by W. HUMBACH.

Safety and Radiation
- "On the External Force Acting on the Marine Reactor Due to Ship Motion in Rough Sea," by E. KAWASHIMA, M. SAKAO and R. TASAKI.
- "On Safety Measures in Power Reactors," by T. JAEGER.
- "Secondary Shield Design of a PWR For Ship Propulsion," by A. M. MONCASSOLI.
- "Studies of Radiation Protection Offered by Construction Material," by E. G. NIEMANN.
- "The Calculation of Composite Shields by the Removal - Cross - Section Method," by S. SASSE.
- "On the Design of Reactor Shielding," by J. SEETZEN.

Gas-Cooled Reactors
- "Nuclear Reactor Installation for Marine Use," by M. C. HARTNELL-BEAVIS.
- "Comments on Current Studies of Gas-Cooled Reactors Destined for Use in Commercial Ships," by a member of the COMMISSARIAT A L'ENERGIE ATOMIQUE.
- "The Maritime Gas-Cooled Reactor Project of General Dynamics Corp.," by a member of GENERAL DYNAMICS CORP.
- "Gas-Cooled Reactors for Steam Turbine Installations in Ships," by J. BUSCH.
- "Some Problems Presented by Helium-Turbine Installations," by W. SPILLMANN.
- "The Conversion of Nuclear Energy Into Electricity and Heat," by K. BAMMERT.
- "Up-to-date Experience with the Research Reactor Geesthacht and a Description of the Experimental Equipment now Being Built," by E. BAGGE.

Special Subsidiary Subjects
- "Instrumentation Problems in Connection with Ship Reactors," by M. G. VALLAURI.
- "Fuel Elements for Ship Reactors," by A. BOETTCHER.
- "Production Control and Acceptance Testing of Fuel Elements," by G. MATZ.
- "The Problem of Guaranteeing Fuel in Ship Reactors," by H. HARDUNG-HARDUNG.
- "Zirconium and Zirconium Alloys as Construction and Canning Material For Ship Reactors," by L. BANGERT.

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the reactor and all associated circuits. The report on the initial design study will be completed in a few months and a decision on what action to take will be made early next year (1960).

The question of initial trials on land versus immediate trials on board has been examined equally carefully and methodically. Proper comparisons have been made in respect of (a) the hazards to crew and population involved in case of an accident, (b) accuracy and reliability of measurement results and (c) the cost and time factors. The Studiengesellschaft is certain that all safety requirements can be satisfied equally well in both cases. Because the proposed ship is to be used for research only it could be stationed indefinitely in remote waters, such as a bay, without affecting the scope of the experimental work, and immediate on-board trials would appear feasible.

Such a procedure has substantial advantages: The overall experimental period of the project will be reduced; the problem of radioactivity interfering with dismantling on land and reassembly on board is avoided; results of tests on board have *a priori* greater affinity to realities of ship operations and, finally, personnel have a chance of adapting themselves to on-board conditions at a comparatively early stage.

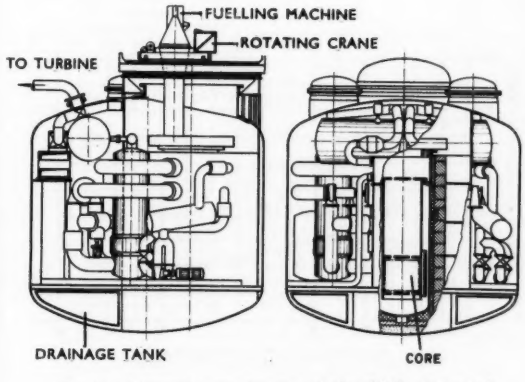

Fig. 2.—General arrangement of the OMR proposed for the tanker "Esso Bolivar."

An Anthology of the Papers

Details of the reactor unit for the "Esso Bolivar" were given in two papers by F. E. Faris and W. Haubold, of Interatom. The former described the reactor aggregate generally and the latter concentrated on Santowax-R, the material used as coolant and moderator.

The "Esso Bolivar" project benefits considerably from the results obtained with OMRE operated for the past two years by the Atomics International Division of North American Aviation and is of a size similar to the Piqua reactor now being built in Ohio, U.S.A., i.e., its maximum power is 40 MW (t). About 30 MW will be required to produce the desired 10,000 s.h.p. (Figs. 2 and 3).

The core, of a diameter of 1.5 m and a height of 1.3 m, accommodates 85 tubular fuel elements. The fuel is 2% enriched uranium alloy sheathed in aluminium alloy but, as an alternative, experiments are in progress with stainless steel-clad uranium oxide rods. The total weight of the uranium charge is 6.9 tons. Provision is made for 19 control rods of boron carbide. The fuel elements and control rods are tested under conditions simulating operating conditions at sea including a list of the ship of 30° and assumed accelerations of the order of 1.2 g up or down, 1.0 g laterally and 0.6 g fore and aft. At full power the quantity of coolant passing through the reactor tank is 3,080 tons/h and the inlet and outlet temperatures are 300° and 322°C respectively. Coolant throughput is constant over the range up to 30 MW. Higher power is obtained by increasing the flow of the coolant.

The coolant purification plant is designed to cope with a decomposition rate of 0.5 kg/MWh but in practice this rate may be lower. The excess amount of polymers formed under irradiation is removed by distillation and stored in special containers. Gaseous damage products are separated from the coolant in a vacuum tank and passed to atmosphere through a funnel, the ship's mast being converted for the purpose. The total coolant requirements for a voyage Bremen-Persia-Bremen do not exceed 30 tons as compared with 2,200 tons of oil in the case of a motor ship with the same s.h.p.

There are two primary coolant circuits and one emergency coolant circuit. If one main circuit was out of action, the ship could still proceed at near maximum speed. The control system is based on the turbine by-pass principle, i.e., on regulation of the steam throughput of the turbine.

The biological shield is formed by light water passing between the steel envelope of the reactor tank and the wall of the containment vessel, the latter having a diameter of 10 m. The final arrangement of the biological shield depends on the outcome of a study conducted jointly by Interatom and the reactor personnel at Geesthacht.

It is confidently expected that prolonged experience with the reactor unit as designed will prove that a higher s.h.p., possibly even 20,000 s.h.p., could be obtained with a reactor of substantially the same size.

The coolant used in the OMR reactor is a mixture of three isomeric terphenyls, known under the trade name of

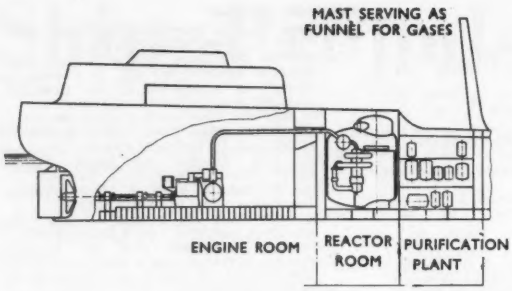

Fig. 3.—Arrangement of reactor and purification plant in the hull.

Santowax - R (Table 1), made by Monsanto in U.S.A. (price 17 c/lb) and in Germany by Bayer-Leverkusen. The composition of the material is: 10% o-terphenyl, 53% m-terphenyl and 36% p-terphenyl. At room temperature, Santowax-R is solid, of neutral colour and waxy consistency. Its melting point is 140°C and its boiling point at atmospheric pressure 370°C.

TABLE 1
PROPERTIES OF SANTOWAX-R

	Temperature: 300°C	
	Polymer content 0%	Polymer content 30%
Specific weight (kg/m³) ..	888	920
Heat conductivity (kcal/mh °C)	0.0995	0.0995
Specific heat (kcal/kg °C)	0.526	0.507
Vapour pressure (atm) ..	0.20	0.27
Viscosity (10^4kg s/m²) ..	36	82

Irradiation in the reactor produces a concentration of high boiling substances (polymers) with a lower volatility than that of the undamaged coolant, and the evolution of gases, the latter forming about 1% (weight) of the total damage products present. See Figs. 4 and 5.

Two papers of special interest were contributed by H. P. Kinsey and H. W. Bowker (U.K.AEA), and W. A. Hepburn and D. H. Specht (Maritime Administration of the U.S. Dept. of Commerce). Both papers report on a study comparing various reactor systems applied to marine application and both arrive at somewhat unexpected conclusions considering the trends in power reactors in the two countries. In fact, the AEA recommends further development of the OMR as potentially the most favourable type whereas the U.S. authority proposes that the gas-cooled (helium) reactor operating in conjunction with a gas turbine may in, say, 10 years' time, offer the greatest advantages.

The British paper deals with the comparative merits of the AGR, GCHWR, PWR, BWR and O(L)MR for the case of a propulsion unit of 22,000 s.h.p. in a 65,000 dwt tanker. Each system provides for an isolated primary coolant circuit coupled via a heat exchanger to the steam circuit incorporating the turbines. The two gas-cooled systems provide superheated steam to the turbines at 850°F, 615 psi and the OMR superheated steam at 559°F, 225 psi. The two light water systems provide saturated steam at 600 psi (BWR) and 450 psi (PWR).

The AGR design is similar to that of the Authority's experiment but has a flat-topped pressure vessel to conserve height. The containment vessel has a diameter of 46 ft. The core follows the design of the AEA AGR experiment. The average rating of the fuel is 10.5 MW/tonne. The GCHWR is of the calandria and pressure tube type. The containment vessel has a diameter of 52 ft. The coolant is CO_2 and the average fuel rating is 7.3 MW/tonne. The PWR layout is similar, in general, to that of the Savannah. The pressure in the coolant circuit is 2,000 psi. The average fuel rating is 13.6 MW/tonne. The BWR unit is largely identical to that described in the A.M.F. proposals in T.I.D. 7539. The pressure in the coolant circuit is 915 psi. The containment vessel is cylindrical, 30 ft in diameter and 45 ft high. The average fuel rating is 14.8 MW/tonne.

The O(L)MR is based on a previous design study of the Authority for a marine unit. The coolant is Santowax-R operated at 30% polymer content and replacement is calculated at 18 lb/MWd. The pressure in the coolant circuit is 150 psi. The pressure vessel is made from carbon steel, has walls of 1¼ in. thickness and a diameter of 10 ft. The containment vessel is cylindrical, 35 ft in diameter, positioned horizontally, and 50 ft long. Average fuel rating—9.9 MW/tonne.

In order to establish a basis for comparison the following assumptions have been made: (a) fuel cost for the conventional ship as shown in Table 3; (b) both conventional and nuclear ship are at sea for 300 days a year and travel at the same speeds, and (c) operational rates are to give a minimum return on capital of 14%—the figure employed in the present study is 15%; (d) two routes are considered: a long voyage—Persian Gulf-Cape of Good Hope-United Kingdom—and a short voyage—Eastern Mediterranean-Thames.

Nuclear fuel cycles and resulting costs are summarized in Table 2. Two sets of fuel costs have been calculated, one for the upper and one for the lower end of a range of fissile material prices extending from £5,000 to £8,000 per kg 93% equivalent U-235. Irradiation was fixed at a maximum of 9,000 MWd/t. At the upper end of the price range and maximum irradiation, the continuous charge/discharge cycle gives fuel costs varying from 0.246 d/shp-h for the AGR to 0.348 d/shp-h for the OMR. In the 100-day batching cycle costs are up to 30% higher, as the average irradiation is reduced to 5,000 MWd/t. In the one-core batching, where the average irradiation of the discharge fuel falls to about 3,500 MWd/t, the fuel costs are increased still further, by about 35%. As shown in Table 2 the AGR has the lowest fuel costs in d/shp-h and initial fuel investment. The liquid-cooled reactors PWR, BWR and OMR show increased fuel costs (and initial fuel investment) in the order given.

The reactor capital costs rise with

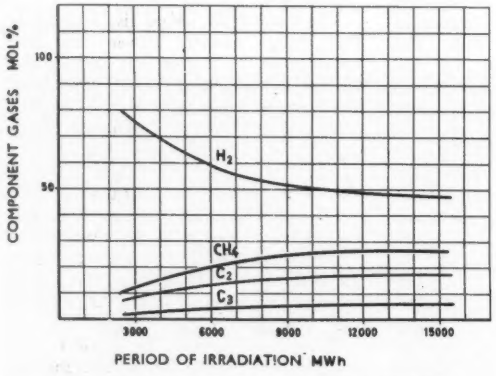

Fig. 4.—Composition of the gas mixture evolved.

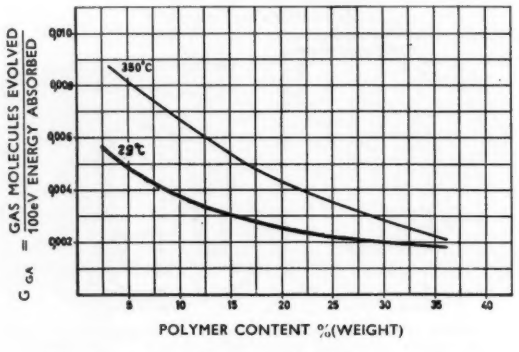

Fig. 5.—Santowax-R: Gas evolution as a result of irradiation.

TABLE 2

SYSTEM		AGR			GCHWR	PWR			BWR			OLMR		
Propulsion power	s.h.p.	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000	22,000
Fuel elements														
Fuel		UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Element design		Solid circular rod			Circular rod cored (MgO)	Solid circular rod			Solid circular rod			Solid circular rod		
Rod diameter over fuel	in	0.30	0.30	0.30	0.50/0.25	0.30	0.30	0.30	0.36	0.36	0.36	0.50	0.50	0.50
Can material		Be	Be	Be	S S	Zr	Zr	Zr	Zr	Zr	Zr	S S	S S	S S
Can surface			Smooth		Smooth		Smooth			Smooth			Smooth	
Can thickness	in	0.040	0.040	0.040	0.015	0.033	0.033	0.033	0.030	0.030	0.030	0.010	0.010	0.010
Number of rods per cluster		35	35	35	19		8,650 total		49	49	49	19	19	19
Fuel assembly wall thickness	in	—	—	—	—	—	—	—	0.078	0.078	0.078	0.020	0.020	0.020
Fuel assembly wall material		—	—	—	—	Zr	Zr	Zr	Zr	Zr	Zr	S S	S S	S S
Fuel assembly channel side over wall	in	—	—	—	—	—	—	—	4.468	4.468	4.468	2.375 inner hex. side		
Coolant		CO_2	CO_2	CO_2	CO_2	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Terphenyl		
Moderator			Graphite		D_2O	H_2O	H_2O	H_2O	H_2O	H_2O	H_2O	Terphenyl		
Fuel costs														
Refuelling programme*		C. C–D	I–C	100 day	C. C–D	C. C–D	I–C	100 day	C. C–D	I–C	100 day	C. C–D	I–C	100 day
Average rating	MW/teU	10.5	10.5	10.5	7.3	13.6	13.6	13.6	14.8	14.8	14.8	9.9	9.9	9.9
Axial form factor		—	—	—	—	—	—	—	—	—	—	—	—	—
Radial form factor		—	—	—	—	—	—	—	—	—	—	—	—	—
Nat. U enriched with U^{235} at £8,000/kg 93% equivalent U^{235}														
Average irradiation of reject fuel	MWD/teU	9,000	3,940	5,750	9,000	9,000	3,180	5,180	9,000	3,390	4,510	9,000	3,580	5,707
Average fuel life	Days	857	375	548	1,233	662	234	381	608	229	305	909	362	583
Cost of initial charge	£m	0.429	0.455	0.421	0.895	0.452	0.482	0.438	0.488	0.542	0.473	0.880	0.957	0.852
Final fuel cost	d/shp/hr	0.246	0.437	0.320	0.348	0.277	0.561	0.384	0.292	0.535	0.417	0.348	0.568	0.421
Nat. U enriched with U^{235} at £5,000/kg 93% equivalent U^{235}														
Average irradiation of reject fuel	MWD/teU	9,000	3,940	5,750	—	9,000	3,180	5,180	9,000	3,390	4,510	9,000	3,580	5,770
Average fuel life	Days	857	375	548	—	662	234	381	608	229	305	909	362	583
Cost of initial charge	£M	0.372	0.390	0.367	0.683	0.372	0.391	0.362	0.376	0.408	0.366	0.638	0.693	0.623
Final fuel cost	d/shp/hr	0.207	0.362	0.268	0.246	0.212	0.453	0.303	0.207	0.401	0.340	0.226	0.370	0.281

* C. C–D .. .. Continuous charge/discharge with full axial reshuffling.
I–C .. .. Replacement of complete core when burn-up of most highly irradiated elements reaches limit of 9,000 MWD/t.
100 day .. .. Replacement at 100-day intervals of fuel which has reached or is approaching maximum burn-up.

increasing weight; thus the lighter liquid-moderated systems tend to have the advantage of lower capital costs coupled with greater cargo capacity. Even so, the total capital costs of ships powered by liquid-cooled reactor units are still about 40% above the conventional.

The conclusion is drawn that no currently developed reactor system can yet be applied economically to marine propulsion, the main difficulty being the high capital cost of a reactor unit. Simplification of the design should be the primary aim and further development work should concentrate on systems offering the greatest scope in this respect. In the context of a 65,000 dwt tanker, the OMR system may be considered the comparatively best proposition from this point of view, whereas the two gas-cooled systems are the least hopeful.

The American authors approach the subject in a slightly different manner. Their study represents an analysis of conditions as they are expected to apply 10 years hence, when various developments now still in an early stage will have matured and been embodied in practical designs, then available to the marine service. Table 5, which extends the period allowed for the improvements envisaged by five years, has been added in an attempt to give a realistic estimate of the full development potential of each of the systems considered in the paper.

The study is concerned with nuclear propulsion units supplying 30,000 s.h.p. The various reactor systems investigated are the PWR, BWR, OMR and the GCR. The first represents an extrapolated version of the "Savannah" plant (20,000 s.h.p.) and the last is based on the helium-cooled closed-circuit gas turbine plant currently under development in the USA (20,000 s.h.p.). Sintered UO_2 pellets are used as the fuel in all cases but the enrichment varies as is indicated overleaf.

The BWR propulsion unit employs a cross-compounded, double-flow turbine driving the propeller through a reduction

TABLE 3

	Conventional 65,000-ton ship	AGR		GCHW		PWR II		BWR		OLMR	
1. CAPITAL INVESTMENT											
Hull and outfit £M	2.90	2.90		2.90		2.90		2.90		2.90	
E.R. propulsion machinery £M	1.20	1.07		1.07		1.12		1.07		1.12	
Reactor and compartment £M	—	3.33		4.03		1.98		1.53		1.58	
TOTAL CAPITAL COST £M	4.10	7.30		8.00		6.00		5.50		5.60	
% increase over conventional	—	78%		95%		46%		34%		37%	
2. ANNUAL OPERATING COSTS*		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Depreciation, Insurance, Profit to owner (15% of capital) £000's	615	1,095	1,095	1,200	1,200	900	900	825	825	840	840
Repairs, Wages, Overheads, Port and Canal charges, etc. £000's	167	184	184	184	184	184	184	184	184	184	184
Fuel oil at 140/- per ton (0.413 d/s.h.p.-hr)	273	—	—	—	—	—	—	—	—	—	—
Nuclear fuel: (based on fissile material cost of £8,000 per kg. 93% equivalent U^{235}) d/s.h.p.-hr	—	(0.437)	same	(0.549)	same	(0.561)	same	(0.535)	same	(0.568)	same
Net nuclear fuel cost, one core batching £000's	—	279	290	350	362	348	370	332	352	360	375
Moderator make-up charge d/s.h.p.-hr	—	—	—	—	—	—	—	—	—	(0.050)	—
Moderator make-up charge £000's	—	—	—	—	—	—	—	—	—	31.7	33
TOTAL ANNUAL OPERATING COST £M	1.055	1.558	1.569	1.734	1.746	1.432	1.454	1.341	1.361	1.416	1.432
% increase over conventional	—	48%	49%	64%	65%	36%	38%	27%	29%	34%	36%
3. COST PER CARGO TON-MILE											
Cargo ton-miles per year $\div 10^9$	35.5	32.6	33.8	32.9	34.0	33.1	35.2	33.4	35.6	33.7	35.1
Cost in pence/cargo ton-mile d	0.0713	0.115	0.111	0.127	0.123	0.104	0.099	0.096	0.092	0.101	0.098
% increase over conventional	—	61%	56%	78%	72%	46%	39%	35%	29%	41%	37%

*Note: Column (a) takes account of the loss of earnings during the refuelling period. Column (b) ignores the refuelling period and assumes 300 days per year at full power, as for conventional ship.

TABLE 4

System	Capital million dollars	Operating efficiency Mills/shp-h 1965 : 1975*			Fuel Mills/shp-h 1965 : 1975*	
BWR	10.6	9.50	27.4	31.0	2.51	2.27
PWR	12.0	12.18	23.6	32.0	4.46	3.58
OMR	10.9	10.77	24.0	29.0	3.05	2.62
GCR	10.9	9.17	35.0	42.0	2.04	1.79

* Based upon predicted system improvements which are given in Table 5.

TABLE 5

System	1965 net efficiency	1965 fuel cycle cost	Estimated 1975 efficiency	Reasons for improvement	1975 cycle cost
MGCR ..	35%	2.04	42%	Higher gas temperature and pressure	1.79
MGCR-Steam	31	2.18	38	Higher gas temperature and pressure. Supercritical steam	1.88
BWR	27.4	2.51	31	Nuclear superheat	2.27
PWR	23.6	4.46	32	Reheat and regenerative feed water heating	3.58
OMR	24	3.05	29	Optimization of cycle and regenerative feed water heating	2.62

gear. The turbine is supplied with dry saturated steam at 5,430°F 980 p.s.i.g. and a vacuum of 28.5 in. Hg. Natural circulation is employed. Initial enrichment of the fuel: 2.67%. Weight of the charge: 7,720 kg. Irradiation: 10,000 MWd/t. Core dimensions: 70.5 in. diameter, 86.4 in. long.

The PWR propulsion unit has two turbines, a high pressure ahead and a low pressure ahead turbine, both being connected to the propeller through a common reduction gear. The turbines are supplied with steam at 460°F, 475 p.s.i.g. and a vacuum of 28.5 in. Hg. Initial fuel enrichment: 4.4%. Weight of the charge: 7,100 kg. Irradiation: 7,352 MWd/t. Core dimensions: 62 in. diameter, 66 in. long.

The OMR propulsion unit has two turbines as described in the preceding system. The turbines are fed with steam at 650°F 425 p.s.i.g. and a vacuum of 28.0 in. Hg. Terphenyl is used as the coolant. Initial fuel enrichment: 3.66%. Weight of the charge: 6,850 kg. Irradiation: 14,000 MWd/t. Core dimensions: 60 in. diameter and length.

The GCR propulsion unit consists of a closed-cycle gas turbine and uses helium as the working fluid. The helium supplied direct from the reactor enters the two-shaft, intercooled, free power type of turbine aggregate at 1,123 p.s.i.g. and 1,500°F at a pressure ratio of 2.6 : 1. The turbine aggregate drives a controllable-reversible pitch propeller through a reduction gear. After leaving the turbine the gas reaches the hot side of a regenerator where it gives up heat, continues to a pre-cooler reducing its temperature still further and then passes in succession through a low pressure compressor, an inter-cooler and a high pressure compressor. Finally, the high pressure gas enters the cold side of the regenerator in order to warm up before re-entering the reactor. Beryllium oxide is used as moderator and graphite as reflector. Initial fuel enrichment: 5%. Weight of the charge: 4,155 kg. Irradiation: 24,000 MWd/t. Core dimensions: 76.5 in. diameter and length.

Capital, fuel and operating costs of the four systems are summarized in Table 4. The figures shown include a plutonium credit of $12/g and are applicable providing more than one of each type is built.

The results of this study indicate that the high temperature gas-cooled system as described offers considerable scope for the development of a highly efficient, technically safe and economically favourable source of power in the field of marine propulsion. The important advantages offered by this system largely stem from the use of a single (gaseous) working fluid only and from the specific properties of helium employed as such. Helium is non-wetting, non-toxic and non-corrosive. The amount of induced activity during operation is expected to be virtually nil. The only problem connected with helium is leakage. Another favourable factor is the high heat capacity of the GCR. Calculations show that cooling could be interrupted for 30-60 minutes before over-temperature conditions develop.

H. Hardung-Hardung (Degussa) dealt with the delicate problem of guaranteeing reactor fuel elements. The paper is interesting because it is conceived from the point of view of the manufacturer solely and exclusively interested in the production and sale of fuel elements and in no way connected with, or responsible for, the construction and operation of the reactors in which the fuel elements are to be used. The author examines the factors which lead to a policy of firm guarantees, for instance in the field of consumer goods where accurate knowledge of the component exists production- and performance-wise, and the more fluid conditions in reactor engineering. While the development of land-based reactors may have advanced to a stage where the fuel element manufacturer might be expected to commit himself in certain cases on certain points beyond pre-irradiation properties of the element, conditions in the ship reactor sphere are such that any commitments on the properties of the fuel element in the pre-irradiated state, let alone its behaviour in operation, would be based on speculation rather than control of relevant factors.

The Atmosphere in the Lobbies

One cannot but feel impressed by the determination of the Germans to develop and build nuclear ships. Germany is proud of its achievements in re-building its merchant fleet—5,000,000 tons. The aim now is to leave nothing undone which may assist in perpetuating Germany's present reputation of owning the most modern of all merchant fleets. There is a strong feeling of urgency around the nuclear ship project.

This is not to convey that the project is solely seen in the light of potential business opportunities and substantial advantages in this highly competitive trade. Thought is actually given to the reserves of primary energy sources. However, 80% of the German merchantmen are motor ships powered by oil. The experts at the conference did not agree whether oil will be plentiful for an infinite period or fall short of demand after the year 2,000. Similar discussions took place on coal. But few of the shipping people are prompted by considerations of this kind when they join in the general call for broader and faster action.

There are signs that this situation could seriously embarrass the Studiengesellschaft and its subsidiary which, of course, have the same psychology as all scientific establishments. Their declared policy of concentrating on one reactor type at a time, dictated largely but not exclusively by limited resources, is not universally accepted. It is certainly significant that some of the Studiengesellschaft's own members have decided in favour of individual action, parallel to the "central" project. Deutsche Werft have joined up with AEG and initiated a BWR project, and Howaldtswerke are engaged in a research study with the Argonaut-type promoted by Siemens.

The Studiengesellschaft enjoys high esteem and great admiration at present but, to the outsider, it would appear that, in spite of its recognized merits as a pioneer, its influence may shrink rather than spread in the years to come. The philosophy of Germany's constitution does not allow the State to take a firm hand in matters of industrial development. On the other hand, a stabilizing influence is clearly needed, at least in the shipping sphere. The Studiengesellschaft could exercise such an influence, so to speak, ex officio. It would be regrettable to see it sink, before the first nuclear ships are afloat.

Electron Beam Welding

A Comparison with Conventional Shielded-arc Methods

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A discussion of the advantages of electron beam welding over conventional argon arc welding methods is made from the viewpoint of control of impurities and welding variables. The principles involved in the application of electron optics to welding are discussed.

CREDIT for the first use of electron bombardment heating effects for welding applications must go to M. Stohr[1], head of the technological services of the French Atomic Energy Authority at Saclay, who pioneered the work about two years ago. Results of American studies of electron beam welding have also appeared in recent literature [2, 3], whilst in this country work is just commencing, principally at various establishments interested in nuclear energy.

The comparatively recent application to welding is surprising since the use of electron bombardment for zone refining[4] and vacuum melting processes has been well established for a considerably longer time. Furthermore, the theoretical and practical aspects of the production and focusing of electron beams can now almost be described as classical physics.

Since its inception for the study of metallurgical melting processes, the use of electron bombardment has become well established as a method of utmost value. The major reason for this in applications other than welding is the lower atmospheric contamination resulting from melting in vacuum, as can be seen from Table 1. The application of the electron beam method to welding, however, offers important advantages other than the purity of the atmosphere.

It is in the nuclear reactor fuel element field that the major use has been made of this process. Indeed, it appears that its original development in France was prompted, not for any advantages that might have derived from its use as a welding technique, but by a commitment which arose to weld fuel element reactor cans in vacuum, to facilitate subsequent pressurizing of the can on to the element, thereby providing good heat transfer characteristics. An internal residual gas which would be present in conventional welding would not allow complete collapse of the can on to the element on pressurizing. However, the lack of the atmosphere within the can further helped the heat transfer problem since it minimized the formation of internal oxide films on the can and fuel element while in use which tend to lower the heat transfer efficiency.

Atmospheric Contamination

This is perhaps the most important advantage the process has over conventional welding methods. Contamination of the weld bead and heat affected zone can result in very inferior properties in that region of a component compared with the properties possessed by the parent metal. The low ductility of molybdenum welds, and the inferior corrosion properties of welds in zirconium alloys, due to the increase in the impurity content of the weld region, are but two examples. Table 1 shows the approximate impurity concentration in various welding atmospheres compared with a vacuum of 10^{-4} mm Hg, which represents a remainder of only 3 ppm of the initial atmosphere.

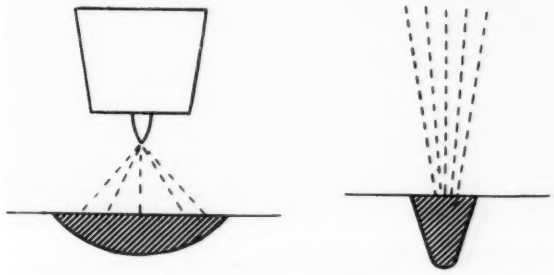

Fig. 1.—Comparison of extent of molten pool. Left; fusion welding with argon arc. Right; electron beam method.

Recent American figures for the level of gaseous interstitial elements in Zircaloy-2 weld material showed no increase in nitrogen and oxygen content and a reduction in hydrogen content compared with the parent material. Corrosion results on these materials showed that the weld area had the same or better corrosion properties than the parent material when exposed to a pressurized hot water environment.

Further evidence of the advantages of low contamination of atmosphere is reported by the Americans in welding a certain type of fuel element can in which a nickel barrier layer is present, extending to the surface between element can and cap. With tungsten arc, inert gas welding, the nickel does not alloy with the aluminium canning in the fusion area and a spike of nickel penetrates the weld area. This is a possible fault line into the element. With the electron beam method complete mixing is achieved and hence no spike is formed. A similar effect is found when welding elements containing a layer of Al-Si alloy between the element and cap. The reason is, presumably, that oxidation of this lower melting point interlayer occurs, which inhibits alloying in tungsten arc welding. The superior atmospheric purity in electron beam welding prevents this oxidation.

A further advantage of the electron beam process from

TABLE 1

Atmosphere	Impurity Concentration (ppm)
Vacuum 1 × 10^{-4} mm Hg	0.1
Helium 99.995%	60
Argon 99.99%	100

a contamination viewpoint is that no contamination from any electrode source is possible, as sometimes occurs in tungsten arc welding.

Recent information also shows that the electron beam method is not confined to joining of metals. Ceramics can be melted and joined and recently attention has been turned to the problems of joining semi-conductors.

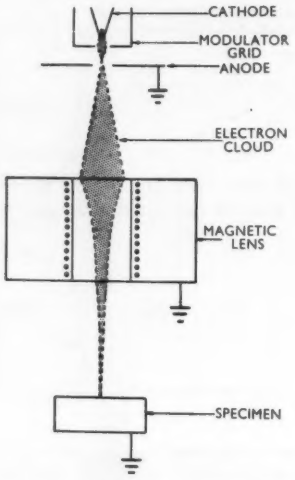

Fig. 2.—Schematic diagram of electron beam focusing.

Control of Welding Variables

Variation of the filament current, voltage, or spot focus, provides easy finger-tip control of the heat input during the welding operation; a particular example being the pre-heating or post-heating of the weld area, which is conveniently achieved by these means. This is particularly useful in materials which are susceptible to hot cracking of welds, or which would normally require some heat treatment after conventional welding. By varying the power or focus of the electron beam, excellent control of heat input is easily achieved, while it is not so easily carried out in arc welding. In arc welding, also, it is not possible to achieve very low heat inputs due to arc instability.

The fact that the electron beam can be focused to a small area whilst still achieving high heat inputs, provides a further significant advantage of electron beam welding over conventional arc welding. Fig. 1 shows, diagrammatically, a comparison between the form of molten weld pool obtainable by the two processes.

The electron beam method is capable of a much higher heat input per unit area than is arc welding. This has a number of advantages from a welding point of view:

(a) It allows thicker sections to be welded whilst minimizing the heat affected zone in the parent metal.

(b) It allows very thin sections to be welded conveniently, both to other thin sections, and also to very thick sections.

(c) The use of a small spot minimizes the vapour loss from the molten pool.

The use of a pulsed beam, in which the heat input can be switched on and off for specified time intervals is more conveniently achieved than in arc welding equipment. Suitable methods of pulsing the beam are described later. The control of this feature is of the utmost importance in vacuum welding highly volatile metals, as gross evaporation of metal from the molten pool into the chamber atmosphere will cause electrical breakdown by discharge. The extent of this vaporization depends on the area of the molten pool (i.e., focused spot size) and the vapour pressure of the metal at the welding temperature. Table 2 shows the mass of metal vaporized per second from unit area at the melting temperature.

TABLE 2

Metal	Temperature °C	Material vaporized per second (g/cm^2)
Al	660	10^{-8}
Zr	1,750	2×10^{-4}
Ta	2,996	1.4×10^{-3}
W	3,382	1.4×10^{-4}
Be	1,280	4×10^{-5}
Mg	650	10^{-3}

The use of this pulsed heat input technique, together with a vacuum pumping system of high capacity, minimizes the chance of this discharge breakdown by allowing the metal atoms to be pumped out of the system during the " off " cycle. By control of the ratio " on time "/" off time " and welding speed, a series of effectively overlapping spot welds can be obtained.

Variation of this ratio can also have other advantages. For instance, if sealing of a component is required under conditions that produce a minimum temperature rise in the surrounding material, the welding can be done in short runs, followed by longer " off " times when the assembly cools down. On the first run, the component is joined by disconnected lengths of weld runs. By suitable timing of this pulsing it can be arranged that these are joined up gradually on subsequent runs, to provide, eventually, a continuous weld.

Economic Advantages

With a suitably designed chamber, and mechanical jigs for location and rotation of a number of specimens, this

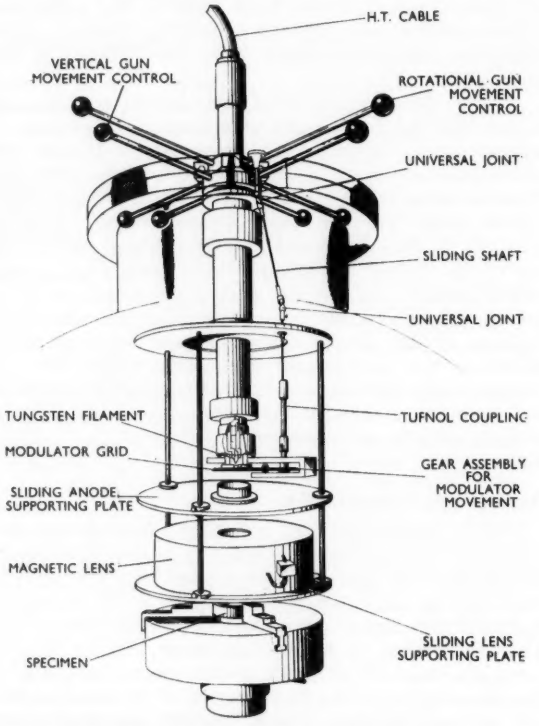

Fig. 3.—Schematic diagram of electron gun assembly.

process is quite applicable to mass production techniques, one pumping operation only being needed for each batch. The process is, in fact, being used both by the French and Americans for the production welding of cans for nuclear reactors. Furthermore, the Americans have quoted[2] some interesting economic comparisons between this process and conventional welding methods. Neglecting capital cost of equipment, and considering only consumable items for each batch (i.e., electrical power requirements, inert gas consumed, etc.) the welding cost for 1,000 fuel elements over a 24-hour period is about $1 for the electron beam process, $7 for inert gas shielded tungsten arc on conventional materials not requiring special facilities, and as much as $35 for the special equipment (inert gas chamber welding) needed for reactive metals. This comparison shows that the process is far from a laboratory curiosity.

Electrical Design Considerations

The basic electrical design necessary for the production of a focused electron beam is comparatively simple. Fig. 2 shows diagrammatically the general arrangement. A high negative potential is applied to an electron emitter, usually a tungsten filament heated by low voltage supply. The electrons are accelerated from the filament towards an anode, usually a disc with a hole in it or a tube at earth potential. The collimated beam emerging then passes through a magnetic solenoid lens which focuses the beam to a spot, the size of which is dependent on the electron optics of the assembly. With an advanced type of electron gun this can be as small as 0.01 mm², but even with very simple optics, a spot size of about 1-2 mm is easily obtainable.

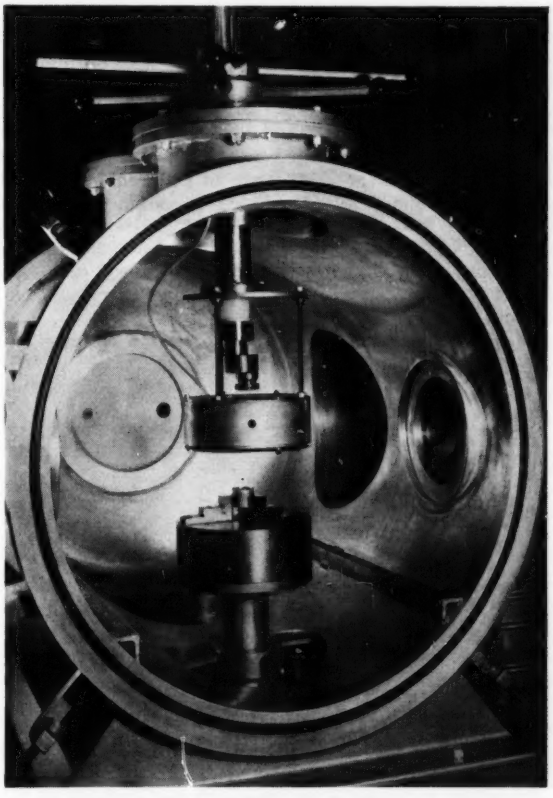

Fig. 4.—Close-up view of interior of welding chamber.

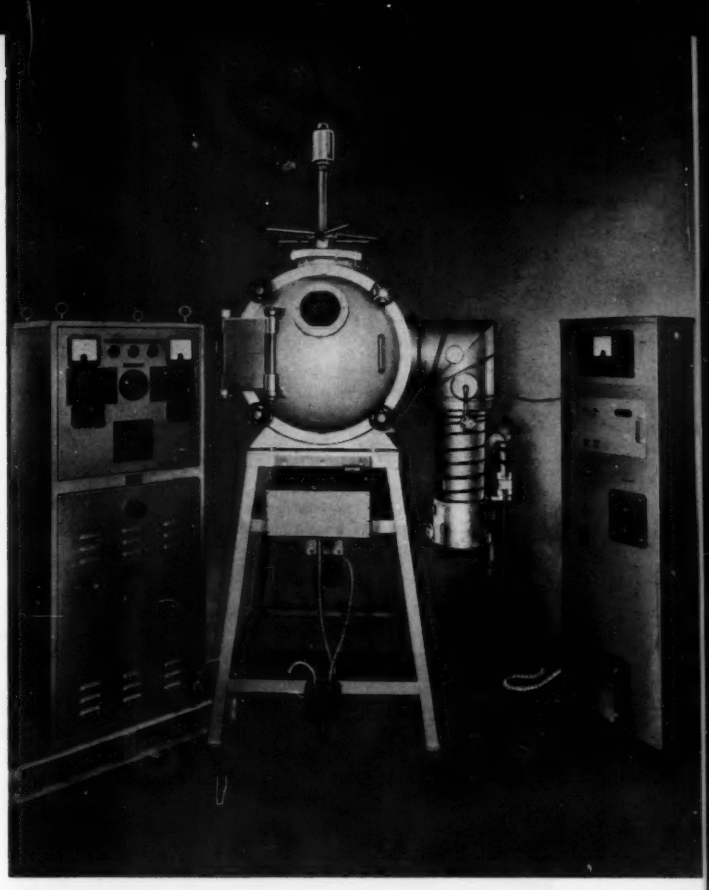

Fig. 5.—Edwards High Vacuum, Ltd., electron beam welding equipment at AWRE.

Normally a modulator grid is placed between the filament and the anode. This again has a small hole to collimate the beam. Its main purpose, however, is an alternative or additional means of focusing the beam. By applying a potential more negative than the filament, the electrons are electrostatically repelled to a narrower beam.

The heating effect at the specimen is governed by the kinetic energy of the electron beam. This is related to:

(a) the speed of the electrons determined by the accelerating voltage—the higher the voltage, the faster the electrons;

(b) the number of electrons in the beam hitting the specimen. This factor—the beam current—can be increased by increased filament current or surface area.

The power input to the specimens can be increased by increasing either of these two variables. However, there are certain limitations. Increasing the HT increases the intensity of X-ray emission and may necessitate shielding the operator from this hazard. About 40 kV is considered the safe limit for a ¼ in. thick steel chamber. (The intensity will, of course, depend on the metal being bombarded.) Increasing the beam (filament) current to produce more electrons gives complications of space charge effect (mutual repulsion of the electrons in the beam) making it impossible to focus to a small spot, if the beam current is too high.

The application of a pulsed or chopped beam produced by reducing the intensity, or even completely stopping the beam, has already been described. Electrically this can be achieved by several means. The way this was done initially in the AWRE equipment was to incorporate a timing unit in the three phase mains input to the power unit supplying the main HT voltage and the bias voltage. This method, however, tends to be very expensive and moreover was found to suffer from a number of

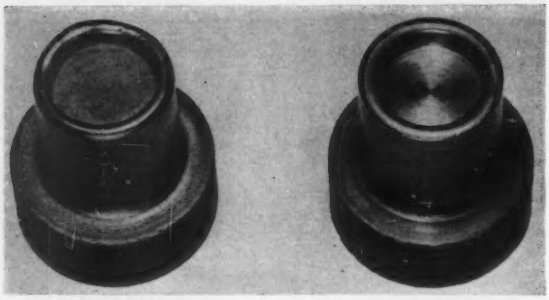

Fig. 6.—Comparison of tube end cap welds in beryllium. Left; argon arc. Right; electron beam.

operational difficulties. For example, alteration of the timing cycle affected the characteristics of the emerging three phase supply and thus upset the calibration of power settings, etc.

An alternative method which is much simpler, less expensive and which does not involve the disadvantages of the earlier method is to apply a superimposed pulse bias voltage to the modulator grid, additional to any bias used for focusing. If this voltage is greater than the "blackout" voltage of the system, the electrons will be prevented from emerging from the grid aperture. The blackout voltage is of the order of 1 kV for a 20 kV, 100 mA beam. This system can utilize a simple single phase mains voltage timing circuit to control the bias circuit.

A third method of pulsing could be to use a timing unit on the feed to the magnetic lens. This would alter the concentrated heat input at focus to a diffused area, and thus produce the desired effect.

Equipment at AWRE

This unit (Figs. 4 and 5) supplied by Edwards High Vacuum Ltd., has a maximum power rating of 20 kV, 100 mA, supplied by a transformer unit which also provides a bias voltage supply to the modulator grid of up to 1 kV. Pulsing of the beam can be applied by two methods. A thyratron type electronic timer unit, cycling the three phase input to the power transformer and pulsing the HT and bias voltage between the limits 0-90 cycles on, 0-90 cycles off relative to mains frequency is provided. Recent modifications have enabled the bias voltage pulsing method to be used. This utilizes a single phase timing unit which switches the bias transformer to give voltage cycling from any value required for focusing purposes to the full value required for blackout. The range of this pulsing cycle is 0.1 sec to 11 secs on, 0.1 sec to 11 secs off.

The gun is housed in a 2 ft diameter by 3 ft long nickel-plated steel chamber, a variable speed drive being provided for specimen movement which is carried out on various jigs for horizontal and vertical rotation and horizontal traverse. With the original equipment it was not possible to reduce the molten pool size on flat plates to below about 2 mm. Consequently several modifications are being undertaken in an attempt to improve the electron optics of the equipment. These include incorporation of an anode of optimum design, adjustment of modulator cathode distance whilst operating, and also adjustment of anode and magnetic lens position. Fig. 3 shows a proposed arrangement of the gun for investigating the effect of these variables.

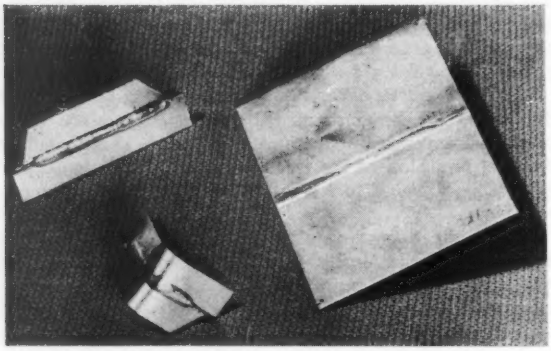

Fig. 7.—Electron beam welds in 0.01 in thick molybdenum sheet: one specimen has been bent through 90° at room temperature.

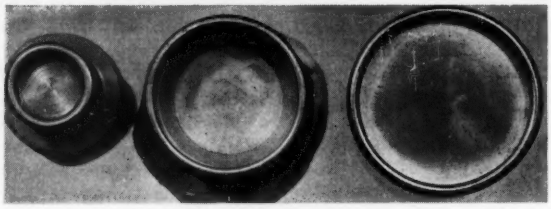

Fig. 8.—Electron beam welds in (left to right) beryllium; aluminium; zirconium.

Excellent welds have been made in stainless steel, pure zirconium, molybdenum and beryllium and have shown the excellent control of welding variables, notably heat input, possible with this method. Fig. 6 illustrates the superior appearance of a beryllium weld made by the electron beam method compared with that done by tungsten electrode argon arc. Further photographs showing the excellent appearance of electron beam weld runs on beryllium, aluminium and zirconium are shown in Fig. 8.

Fig. 9.—Electron beam weld in copper; flange and tube are both $\frac{1}{4}$ in. thick.

REFERENCES

1 Stohr, J. A., *Nuclear Power*, June 1958, and *Bulletin d'Informations Scientifiques et Techniques*. C.F.A. Paris. March, 1958.
2 Wyman, W. L., and Steincamp, W. I. Report No. HW-55667 of U.S. AEC, April, 1958.
3 Wyman, W. L., *Welding Journal*, February, 1958.
4 Davis, M.; Calverley, A.; and Lever, R. F. *Jnl. Applied Physics*, 1956. 27 (2) pp. 195-196.

Radiation-Resistant Greases

An Investigation into Reactor Lubrication Problems

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The effect of heavy radiation on lubricants is a problem confronting all designers of charge machines and control mechanisms. Some results obtained in the development of greases to withstand radiation are discussed here.

WITH the advent of nuclear power plants, lubricants will have to function satisfactorily under nuclear radiation. In stations now under construction there are many applications where grease lubrication can be used to advantage over other methods. Grease, being a semi-solid, is self-sealing and thus can be easily retained in an assembly without the aid of elaborate seals. In addition, it provides an effective barrier against the ingress of dirt and protects the working surfaces against corrosion.

Typical applications where grease can be used are in the control rod mechanisms and charge-discharge machines both containing rolling bearings and gears which have to operate under the combined effects of radiation and high temperature. In the case of the U.K. gas-cooled reactors, the mechanisms will operate in an atmosphere of carbon dioxide at relatively high pressure (150 to 200 p.s.i.). The temperatures will initially be in the range 100°C to 150°C but are expected to rise to 200°C in later designs of reactors. When spent fuel elements are being replaced, the charge-discharge machine will operate for short periods in air at temperatures of about 100°C. A high melting point, thermally stable grease is therefore required, which will be little affected by carbon dioxide and nuclear radiation.

Conventional greases consist of petroleum hydrocarbon oils and are " gelled " (i.e., thickened) by the incorporation of metallic soaps, (e.g., lithium hydroxystearate). The maximum safe operating temperature for a premium quality soap-base grease is about 135°C, and these are therefore unsuitable for the temperatures envisaged. Moreover the soaps are not very stable to radiation and greases gelled with these materials soften and become fluid at quite low radiation dosages[1, 2] (about 0.4×10^{18} n/cm^2).*

It has been found that certain inorganic materials can be used as gelling agents and have the advantage of possessing very high melting points. For instance greases incorporating a special form of silica (non-crystalline and non-abrasive) instead of metallic soaps, treated with a special radiation resistant waterproof material, offer a high degree of radiation stability and have a melting point in excess of 300°C.

The study of the effects of radiation on greases has so far been confined to evaluating the products on laboratory tests,[1, 2] e.g., drop point, penetration, mechanical and roll-stability, etc.; and in standard bearing rig tests[3] in air after irradiating the grease in glass tubes under static conditions. These tests, however, do not adequately cover the operating conditions prevailing in the U.K. reactors, where the grease will have to function under the combined effects of radiation and high temperature in a CO_2 atmosphere. More recently work has been reported,[4] which is an advance on previous test methods, where a modified Shell roll tester was used for studying the degradation in mechanical stability of the grease when subjected simultaneously to shear and radiation.

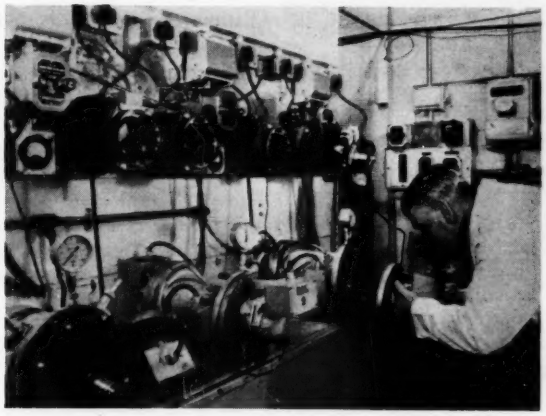


Fig. 1.—Out-of-pile high temperature bearing test rigs.

This article is primarily concerned with the performance testing of greases in rolling bearings under certain reactor operating conditions, and includes tests carried out under hitherto unexplored conditions, the bearing and grease being examined under the combined effects of radiation and high temperature in a CO_2 atmosphere. Additional tests were made in air at high temperature, since reactor equipment will be required to operate for short periods under such conditions.

Types of Greases Examined

A description of the greases examined on the various bearing rigs is as follows:

Radiation-resistant Grease A. This is a silica-based grease containing an acid and earth-treated naphthenic mineral oil, and was developed to give a high level of radiation stability. On static radiation tests in BEPO, this grease was stable to a dosage exceeding 1.8×10^{18} n/cm^2.

Radiation-resistant Grease B. This also is a silica-based grease but contains a more viscous solvent extracted paraffinic mineral oil to obtain greater thermal stability. It has a lower radiation stability compared with grease A, its maximum permissible static dosage being about 1.0×10^{18} n/cm^2.

Radiation-resistant Grease C. This is the same as grease A but contains 5%w graphite, incorporated to provide

* In this paper the dosage is quoted in terms of the easily measured slow neutrons, although the associated radiation, fast neutrons and gamma rays, was principally responsible for the effects observed. A radiation dosage of 1.0×10^{18} thermal neutrons/cm^2 in the pile experiments is approximately equal to 1,000 Mrad as regards the effect produced on hydrocarbon oils.

additional lubrication under sliding conditions at high temperature. Graphite was chosen rather than molybdenum disulphide in view of its excellent nuclear properties.

Radiation-resistant Grease D. This is the same as grease B but contains 5%w graphite. Its radiation stability is equal to that of grease B.

Premium-quality Conventional Grease. This is a lithium base grease containing a solvent-extracted naphthenic mineral oil. It was included in the test series to confirm that a conventional premium-quality soap-base grease would not be suitable for operating at 150°C in the presence of CO_2.

Performance Tests in Ball-bearing Rigs

The bearing tests on the radiation-resistant greases fell into four groups:—

(a)(i) Tests on the unirradiated greases at temperatures of 150 to 200°C in an atmosphere of carbon dioxide at relatively high pressure.

(a)(ii) Comparative tests on the same greases following static irradiation to a high dosage in the BEPO pile at Harwell.

(b) The ultimate test of running the greases in bearings under the combined effects of radiation, high temperature, and carbon dioxide, to simulate reactor operating conditions fully.

(c) Tests on the unirradiated greases in air at 100°C.

Tests Before and After Static Irradiation

Tests on the greases, before and after static irradiation [referred to in groups a(i) and a(ii)] were carried out in the "Carbon Dioxide" rigs illustrated in Fig. 1. The apparatus consists of a ¼-h.p. electric motor, the motor shaft being supported at each end by a test bearing (20×47×14 mm all-steel ball bearing). This is a type commonly used in specification performance testing but was specially heat treated to withstand high operating temperatures. The cage or ball separator fitted to this bearing is of pressed steel.

The bearings were rotated at 1,450 r.p.m. under light load and their temperature maintained at the desired level by electric heaters. The whole assembly was contained in a pressure vessel which was filled with carbon dioxide at a pressure of 100 p.s.i. As the vessel was not completely gas-tight, carbon dioxide was fed (*ca.*20/25 ft^3/week) continuously to the assembly to maintain pressure.

The power consumption of the motor was checked by current measurement, any increase in current showing an increase in friction within the bearings. The rigs were run continuously for 100-hour periods and then stopped and cooled to room temperature before restarting. This procedure revealed any excessive friction on restarting, caused by the grease being too thick and dry at room temperature. Failure of the grease was indicated when an excessive motor current was recorded on restarting, or by rough running of the test bearings. At suitable intervals the pressure vessel was opened up to enable the grease and bearings to be examined for any major change.

In the first series of tests in the CO_2 rigs the radiation-stable greases A and B were tested before irradiation and compared with a premium-quality lithium-base grease. The second series of tests were made on the radiation-stable greases, following their static irradiation, to determine the influence of radiation on grease performance. In the third series of tests a comparison of greases C and D with greases A and B before irradiation was made to determine what influence the incorporation of graphite had on grease performance.

Since shielding of the bearing against "windage" (i.e., ventilation effects) is known to be important at high

RADIATION-RESISTANT GREASES

TABLE 1. Bearing rig tests in carbon dioxide at elevated temperatures

Grease ref.	Drop point °C	Type of shield fitted to bearing to eliminate windage	Test temp. °C	Duration hours	Comments
Conventional grease of premium quality (lithium/solvent-extracted naphthenic mineral oil)	190	Conventional end-covers	150	800	Grease liquefied after 250 hours. Severe grease loss. Bearing rough, inadequate grease supply.
Radiation resistant Grease A (silica/acid and earth treated naphthenic mineral oil)	>300	None	150	100	3-repeat tests. Grease dried out.
		Thin metal shields	150	1,150	Grease dried out gradually, bearing eventually becoming rough.
			150	1,250	
		Conventional end-covers (most effective type of shield)	150	5,600	Grease did not stiffen significantly until after 4,500 hours.
		Thin metal shield	200	400	Grease dried out, bearing rough.
		Conventional end-covers	200	630	Grease dried out, bearing rough.
Radiation resistant Grease A. After irradiation to a dosage of 1.8×10^{18} n/cm²	>300	Thin metal shields	150	1,140	Grease softened considerably but adequate supply retained in the bearing. Eventually became dry and powdery.
		Conventional end-covers	150	3,100	Grease softened considerably but adequate supply retained in the bearing. Grease gradually dried out after 2,000 hours.
Radiation resistant Grease B (silica/solvent extracted paraffinic mineral oil)	>300	Thin metal shields	150	6,000+	Still satisfactory.
				4,000+	Still satisfactory.
		Conventional end-covers	150	7,000+	Still satisfactory.
				4,000+	Still satisfactory.
		Thin metal shield	200	2,800	Grease dried out. Bearing rather rough.
Radiation resistant Grease B. After irradiation to a dosage of 1.0×10^{18} n/cm²	>300	Thin metal shields	150	400	Grease liquefied after few hours. Severe grease loss. Bearings rough, inadequate grease supply.
		Conventional end-covers	150	400	
Grease B after irradiating to a dosage of 0.5×10^{18} n/cm²	>300	Thin metal shields	150	1,000+	Still satisfactory.
		Conventional end-covers	150	1,000+	Still satisfactory.
Grease C (Grease A containing 5%w graphite)	>300	Thin metal shields	150	1,010	Grease dried out, bearing rough.
		Thin metal shields	150	1,150	Grease dried out, bearing rough.
		Conventional end-covers	150	3,400	Grease dried out, bearing rough.
Grease D (Grease B containing 5%w graphite)	>300	Thin metal shields	150	5,100+	Still satisfactory.

NOTE.—These tests refer to a 20 mm all-steel ball bearing, running at 1,450 r.p.m., in a CO_2 atmosphere at 100 p.s.i. A dosage of 10^{18} n/cm² is approximately equal to 1,000 Mrad.

temperature, the effects of different types of bearing shields were also examined.

The results obtained in the above tests are shown in Table 1. The first series of tests showed that the radiation-resistant greases A and B did not liquefy in the bearing, whereas the conventional lithium-base grease liquefied in a relatively short period and lubrication failure soon followed, owing to the excessive grease leakage that occurred. This result was expected, since the maximum safe operating temperature for the industrial premium-quality soap-base grease is about 135°C.

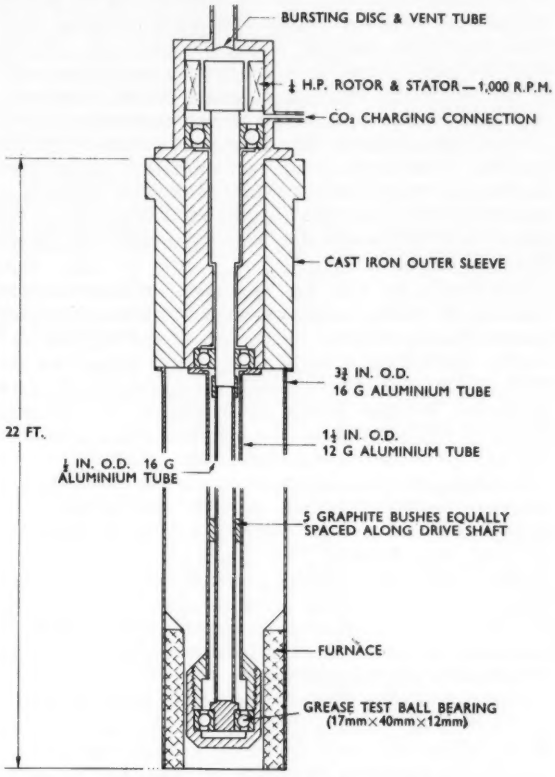


Fig. 2.—Diagram of in-pile bearing test rig.

The second series of tests showed that the more radiation-stable grease A was satisfactory for over 5,000 hours (six months) at 150°C and for about 600 hours at 200°C. The less radiation- but more temperature-stable grease B gave a sevenfold increase in life at 200°C compared with grease A under comparable conditions, and is giving a much increased life on the tests currently being run at 150°C.

The effects of high static irradiation on the radiation-resistant greases is found to affect their mechanical stability. Thus grease A, after a dosage of 1.8×10^{18} n/cm^2 softened appreciably during the early stages of running-in the bearing but, because sufficient grease was retained in the bearing, the lubrication life was not greatly reduced. With grease B, which is designed for high temperature at the expense of some radiation resistance, the grease, after a dosage of only 1.0×10^{18} n/cm^2, liquefied completely and gave premature bearing failure. At a reduced dosage of 0.5×10^{18} n/cm^2, however, grease B showed no evidence of

Editorial Note: Readers may care to know that the three greases referred to in the above article as A, B and D, can be identified as Shell APL 700, 701, and 702 respectively.

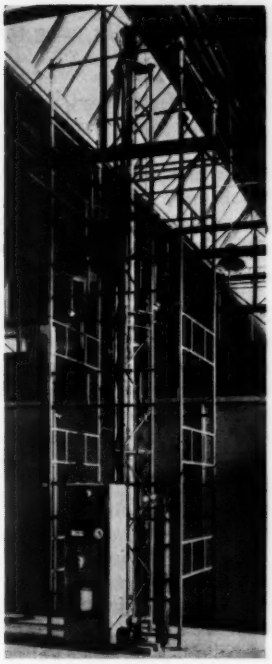


Fig. 3. — In-pile bearing test rig assembled in its transit framework.

liquefaction—or even softening—after 1,000 hours' operation at 150°C.

The incorporation of graphite into the greases appears to have little effect on operating life in rolling bearings under the test conditions used. This is contrary to the widespread belief that such fillers are detrimental in rolling-bearing greases.

The results also emphasize the importance of shielding the bearing against windage when operating at high temperature and high speed. For example, with a totally unshielded bearing drying-out of the grease occurred rapidly and the bearing was too rough for further operation after 100 hours at 150°C. When thin metal shields were fitted to each side of the bearing, drying-out of the grease was at a slower rate, and about a tenfold increase in grease life was obtained. The best performance was obtained with the bearing housed between conventional end-covers which have a fairly wide sealing surface on the

TABLE 2

Results of "in-pile" tests in BEPO

Grease ref.	Total radiation dosage n/cm^2	Comments
Radiation-resistant grease A (silica/acid and earth treated naphthenic mineral oil).	1.8×10^{18} 2.7×10^{18}	Grease and bearing in excellent condition.
Grease A but slightly more viscous oil.	2.7×10^{18}	Grease had stiffened and caused some resistance in the bearing at room temperature.
Radiation-resistant grease B (silica/solvent extracted paraffinic mineral oil)	1.0×10^{18} 1.8×10^{18}	Grease and bearing satisfactory. Grease much harder and tacky, causing much resistance in bearing at room temperature.
Grease B but with less viscous oil.	1.0×10^{18} 1.8×10^{18}	Grease and bearing satisfactory. Grease tacky and slightly granular. Very slight resistance in the bearing at room temperature.

NOTE. These tests were carried out on a bearing running at 1,000 r.p.m., in a CO_2 atmosphere at 50 p.s.i., and 150°C. Thermal neutron flux 10^{12} n/cm^2, sec.

shaft. With this type of seal the grease life was 3-5 times greater than when using thin metal shields.

" In-pile " Tests

Concurrently with the tests described above a special apparatus was constructed for operation in BEPO, so that the more suitable greases could be tested under the combined effects of nuclear radiation, carbon dioxide, and mechanical working in a bearing at high temperature.

A schematic layout of this apparatus is given in Fig. 2, and the assembled rig complete with its transit framework is illustrated in Fig. 3.

In this apparatus the test bearing was located at the end of a 20-ft long aluminium tube extending into the centre of the pile, the driving motor being situated at the opposite end of the tube, above the biological shield. The arrangement was such that the test bearing could be removed by mechanical aids and a new one inserted for further tests.

As pure aluminium possesses low neutron absorption properties, this material was used wherever possible for the rig parts extending below the biological shield. The test bearing (17×40×12 mm) unshielded against windage, was located inside an oven for raising the temperature up to 200°C. The inner race of the test bearing was rotated at 1,000 r.p.m. by the electric motor through a 20-ft long, ½-in. diameter aluminium tube, which was supported in graphite bushes, spaced at regular intervals along its length, in order to reduce whip to a minimum. The whole assembly was hermetically sealed for running the bearing in CO_2 under a pressure of 50 p.s.i. Before commencing each test the assembly was evacuated and flushed with carbon dioxide several times to remove all traces of air.

Typical results obtained in this apparatus are given in Table 2 and show that grease A was stable up to the very high dosage of 2.7×10^{18} n/cm² (about 2,700 Mrad). The same grease, with a slightly more viscous oil, was not quite as good, although still in usable condition at this high dosage.

Grease B was satisfactory up to a dosage of 1.0×10^{18} n/cm² but at 1.8×10^{18} n/cm² the grease became hard and tacky, and caused much resistance in the bearing. A similar grease based on a less viscous oil gave only slight resistance in the bearing, owing to the grease being tacky, after receiving a dosage of 1.8×10^{18} n/cm².

Tests on Unirradiated Greases in Air

Although the majority of the mechanisms exposed to nuclear radiation in a U.K. gas-cooled reactor operate in an inert atmosphere, the reactor charge and discharge machines will be required to operate for short periods in air at temperatures of about 100°C when the spent fuel elements are being ejected. Since under the latter conditions greases are susceptible to oxidation it is necessary to check the stability of greases under such conditions.

For this purpose a 1¼-in. bore ball bearing fitted with a race-centred yellow metal cage was packed with the test grease and run at a speed of 2,000 r.p.m. in air at 100°C. This type of bearing is in common use; the cage metal accentuates oxidation effects.

Under these conditions both greases A and B were satisfactory for periods exceeding 1,500 hours, which is considerably more than the total time they would be required to function in air on nuclear equipment.

Conclusions Drawn from Tests

The in-pile bearing rig tests at Harwell show that greases can be made which will operate satisfactorily at elevated temperatures in the presence of carbon dioxide to the very high dosage of 2.7×10^{18} n/cm². Conventional greases can only be expected to withstand about 15-20% of this dosage[1] and then only at reduced temperatures.

The performance of the greases in the " in-pile " bearing-rig was in the order expected from static radiation tests.[1] Thus grease A based on naphthenic type mineral oil containing relatively high proportions of naturally occurring aromatic compounds was superior to grease B based on a paraffinic type oil. Also in each class the oil of low molecular weight was the more radiation-stable.

The results obtained in the " Carbon-dioxide " rigs with the statically irradiated greases were not in complete agreement with those obtained in the " in-pile " rig. In the latter, no grease softening or liquefaction occurred whereas in the former rigs softening of grease A and liquefaction of the grease B occurred even though these had received a much lower dosage. This difference is attributed to the fact that in the in-pile rig the excess grease is cleared from the bearing before radiation has reduced its mechanical stability, whilst in the other rig the bulk of highly irradiated grease receives considerable shearing during this initial clearing process.

The tests in the CO_2 rigs emphasize the importance of shielding the bearing against windage. A greatly extended grease life was obtained by the use of conventional end covers, which have a fairly wide sealing surface on the shaft. Thin metal shields which are commonly fitted to pre-packed bearings gave a much reduced life and with totally unshielded bearings the life was only 2% of that obtained with conventional end covers.

Although the tests on grease B are not yet complete, results so far obtained show that this more temperature-stable grease will give a substantial increase in operating life over that obtained with grease A where radiation dosage is low. Both greases operated satisfactorily when run in a bearing at 100°C in air for periods considerably in excess of the total time the reactor charge-discharge mechanism will be required to function in air, when spent fuel elements are being replaced.

When considering the lives obtained in these rig tests it should be borne in mind that less critical conditions, i.e., lower temperature, much lower speeds and stagnant CO_2 atmosphere, will occur in service on such applications as the control-rod mechanisms of the reactor. Under these less critical conditions a much longer grease life can be expected.

In conclusion, these tests have shown that greases have been developed which are suitable for lubricating certain mechanisms in nuclear power plants which are subject to high dosages of nuclear radiation at temperatures up to at least 150°C in an atmosphere of carbon dioxide.

Acknowledgments

The authors wish to express their thanks to the Directors of Shell Research, Ltd., for permission to publish this paper. In addition they gratefully acknowledge the assistance given by the staff of the A.E.R.E., and in particular Mr. A. Emmerton and Mr. J. Wright, in carrying out the pile irradiation experiments.

REFERENCES

1. David, V. W., and Irving, R. " Effects of nuclear radiation on hydrocarbon oils, greases, and some synthetic fluids." I.Mech.E. 1957 Conference on Lubrication and Wear, paper 70, p. 543.
2. Carroll, J. G. and Calish, S. R. " Some effects of gamma radiation on commercial lubricants." *Lub. Engineering* **13**, 7.
3. Carroll, J. G., Bolt, R. O., and Hotten, B. W. " Radiation Resistant Greases." *Lub. Engineering* **13**, 3.
4. Handschy, J. R. A., Armstrong, J. W., and Gordon, B. E. " Greases stable to radiation under dynamic conditions." *Lub. Engineering* **14**, 7.

Waste Disposal

Report on the International Discussion at Monaco

IN 1958 the United Nations Conference on the Law of the Sea passed a resolution recommending that the International Atomic Energy Agency should help States draw up internationally acceptable standards and regulations for controlling the release of radioactivity to the sea. IAEA subsequently set up an expert panel to discuss the technical problems and, in conjunction with U.N.E.S.C.O., arranged a conference on waste disposal at Monaco in November.

The conference was opened by speeches from Prince Rainier, Dr. Veronese, Director-General of U.N.E.S.C.O., and Mr. Sterling Cole, Director-General of IAEA, who all emphasized the international nature of the problems and the need for co-operation between specialists of different kinds.

Treatment and Processing

The next three sessions dealt with the treatment and processing of wastes and the general methods of disposal. The papers were mainly descriptive and in the short time available for presentation could not be very detailed. The full texts, to be published in the Proceedings of the Conference, should be of greater value. It was clear, however, that there is a general similarity of technique between different countries in this field, although the emphasis depends on the local geographical features. Ground disposal of low and intermediate packaged wastes was described by both the French and the Canadians, both of whom use concrete-lined trenches subsequently filled in with concrete. Rather surprisingly, the French regarded this as a temporary arrangement pending the transfer of the waste to a form of ultimate disposal not yet settled. Mention was made of the storage of the primary high-activity fission-product wastes, and there was considerable interest in papers by Watson, Aiken and Bancroft (Canada) and by Zimakov (U.S.S.R.) on the incorporation of fission products into glass-like materials. The volatility of some of the fission products gives rise to some technical difficulties, but on a pilot plant scale the Canadians had used air-cleaning techniques to reduce the activity of the gaseous effluent to about 1 in 10^8 of the total fission products incorporated into the glass. Leaching tests had not yet been continued long enough to give final answers, but it appeared that a total of about 1 in 10^4 of the fission products might ultimately be leachable. It thus seemed likely that storage in direct contact with ground water would not be feasible. One of these sessions included a short description of the work associated with the discharges of liquid waste to the Irish Sea from Windscale. As on previous occasions, this work attracted considerable interest and some slight criticism, of which the Russian was the most outspoken.

In a session on the administrative problems of waste disposal, British and American papers (by Dunster and Wolman) outlined the ways in which the recommendations of the International Commission on Radiological Protection could be used as a basis for controlling waste disposal in a scientific manner. The application of these recommendations was not regarded as a simple process and it was considered that not only would management have to adopt a scientific attitude to the problems, but that governments would need, in the American phrase, " to adopt a regulatory position." The recently published Radioactive Substances Bill and the explanatory White Paper[1] make it clear that the U.K. Government have accepted this requirement and, indeed, are prepared to maintain detailed control over the disposal of radioactive waste by individual managements.

Marine Disposal

The legal implications of any marine disposal were thoroughly explored in an American paper by Hydeman, which concluded that present international law did not give individual states sufficient power to prevent damage to their interests nor even to obtain redress if damage occurred. Hydeman thought it likely that an international legal convention would ultimately have to be adopted to allow adequate international control of waste disposal. This suggestion produced forceful opposition from Romanov, a Russian lawyer, who took the position that the international character of the sea made any release of radioactive wastes to it unacceptable. He considered it would thus be wrong to agree on any standards or legal conventions on the subject. Both British and American speakers criticized the absolute nature of this claim, which they considered to be unnecessarily restrictive and, indeed, impracticable.

The next sessions dealt with the biological and physical aspects of disposal into the sea, and it became clear that, although much was known about a few specific situations, it was still difficult or impossible to apply this information to other cases. This difficulty led to a certain amount of pessimism about sea disposal, although this should have been largely dispelled by an excellent paper by Pritchard, of John Hopkins University, who showed by general arguments and samples, how the I.C.R.P. recommendations could be combined with a conservative (i.e. safe) interpretation of current knowledge to give quantitative estimates of permissible discharges to any part of the sea. A committee of the U.S. National Academy of Science, under Pritchard's chairmanship, has recently applied this technique to the disposal of waste from nuclear ships[2], and it was also the basis of the preliminary estimates of the safe discharges from Windscale[3]. Hydrographic and oceanographic techniques and results were also discussed in these sessions and several specialists took the opportunity to call for the prohibition of all waste disposal to the sea, at least until further information was available.

The last session on marine problems took the form of panel discussions on the necessary research work. The conference made no attempt to agree on priorities, but there appeared to be special emphasis on the mixing processes of coastal waters and of the surface layers of the ocean and on biochemistry and physiology.

Ground Burial

The sessions on disposal into the ground produced little controversy. The disposal of large amounts of low and intermediate activity wastes into the ground at Hanford[4] was again described and, although some of the subsequent questions implied that the questioners were not fully convinced of the safety of the operation, there was no direct criticism. Possibly the obvious suitability of the Hanford geology disarmed the potential critics.

Although the Monaco Conference concentrated on the marine problems, it was pointed out that by far the greatest part of the fission product activity would almost certainly continue to be the concern of the geologist. British geologists stated that the intensive use of mineral resources and ground water in the U.K. had to be given special consideration in considering ground disposal in this country and might limit its application.

REFERENCES

1. " The Control of Radioactive Wastes." (Cmnd. 884. H.M. Stationery Office, 1959.)
2. " Radioactive Waste Disposal from Nuclear Powered Ships." (National Academy of Sciences, National Research Council Publ., 658.)
3. Dunster, H. J. " The Discharge of Radioactive Waste Products into the Irish Sea." Part 2. The preliminary estimate of the safe daily discharge of radioactive effluent. (International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955. Paper 419. Vol. 9, p. 712.)
4. Brown, R. F., *et al.* " Experience in the Disposal of Radioactive Wastes to the Ground at Two Production Sites." (Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958. Paper 1767. Vol. 19, p. 95.)

Technical Papers and Publications

THE INSTITUTION OF MECHANICAL ENGINEERS

Effect of Nuclear Radiation on Engineering Materials. By Prof. A. H. Cottrell, B.Sc., Ph.D., F.R.S. (The 46th Thomas Hawksley Lecture).

The extent to which theory could assist practice was the main theme of this year's Thomas Hawksley Lecture. Neglecting effects on the magnetic and electrical properties, the creep strength of alloys, or corrosion resistance, radiation damage could be classified into three main types.

In *electronic* damage, electrons were knocked out of their orbits into states of higher energy; organic materials were most sensitive to this type of damage; particularly the long chain polymers, which changed so rapidly as to be practically useless as reactor materials, which raised difficulties regarding insulation and lubrication. Metals at the other end of the scale were virtually immune; in between, a range of inorganic solids, such as glass and semi-conductors, were sensitive as regards certain of their properties, but not subject to wholesale degradation.

In *transmutation* damage, different elements were formed, often emitting sufficient energy in the process to produce severe electronic and knock-on damage.

In *knock-on* damage, an entire atom was knocked out of its place in the material by a heavy collision from a nuclear particle—often so violently that it, in turn, knocked a whole cascade of other atoms out of place, forming a *spike* of radiation damage. In a crystalline solid, a displaced atom left behind

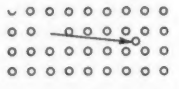


Fig. 1.—Diagram of vacancy and interstitial defects due to the displacement of an atom in the lattice.

a vacancy, or hole of one atomic volume, and came to rest in some place between the crystal layers, as an interstitial, somewhat as visualized in Fig. 1. A spike, visualized in Fig. 2, consisted of an elongated cluster of point defects, with vacancies in the centre, and interstitials mainly round the rim, the width of the cluster being about 10^{-6} cm. Estimates could be made of the approximated number of atoms displaced per collision, in various materials.

During the life of a reactor every one of its atoms would be displaced at least once, and the fact that some materials could retain their original shape and properties was due to the ability to anneal out their damage, metals annealing at much lower temperatures than other materials, aluminium, for example, being practically unaffected by fast neutrons down to temperatures of −50°C. The ability to anneal out damage was clearly most vital in the case of fuels. With uranium, having some 10^4-10^5 atoms displaced per fission, it could be said that each and every atom was displaced during two weeks' operation in a power reactor.

Other materials did not anneal so rapidly as metals. Graphite, for example, retained most of its point defects until much higher temperatures. The theory of stored energy in graphite was briefly explained; it was stored in the vacancies and interstitials, partly as broken atomic bonds round the vacancies, and partly as strain energy at places where the hexagonal layers of the graphite crystal were sprung apart to make room for interstitials. The amount of energy stored could be as much as $\frac{1}{16}$ of that available by burning the graphite.

Radiation hardening of metals occurred in a similar way to alloying; since point defects were somewhat similar to foreign atoms. The nature of the plastic deformation process in crystalline materials was that one block of the material slid across another on a *slip plane*. Slip did not occur simultaneously over an entire plane, but started at a few places, and spread out in a series of concentric wave fronts expanding to cover the entire plane, the line of the front being called the *dislocation line*. The yield strength of a metal or alloy, which contained large

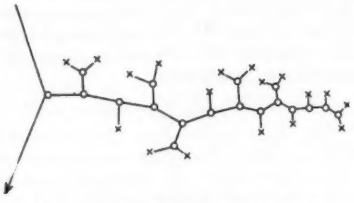


Fig. 2.—Diagram showing a "spike" of displaced atoms.

numbers of dislocations, was determined by the stresses to start these moving and keep them moving over the whole slip plane. Hardening occurred when these were prevented from moving; in some types of alloy hardening this occurred by "pinning" of the dislocations with foreign atoms that had migrated into them. More general alloy hardening was caused by a dispersion of foreign atoms throughout the crystal. With point defects playing the part of foreign atoms, it was to these effects that radiation hardening was attributed. Dispersion hardening, by raising the yield stress in mild steel, also raised the transition temperature, so that the radiation embrittlement of steel could be explained on this basis.

The most serious practical effects of radiation damage occurred within the uranium itself, and a theory had been developed, based upon stresses around a fission spike, to account for the radiation growth. Swelling due to the formation of gas pockets was another important effect.

Radiation damage, it was emphasized, is now so large a subject that it was not possible to cover more than a small part of it in a single lecture. Much of the matter discussed had, until recently, been theoretical, but the electron microscope had now made it possible actually to see dislocations inside metals.

It was necessary to exploit theory to its fullest extent in selecting, planning, and interpreting experimental work. Radiation damage involved displacement of atoms, and the creation of various lattice defects, and modern metallurgical theory provided a powerful tool for attacking the problems, since it was now able to make qualitatively reliable predictions on these, and their effects on materials. A trial-and-error approach to the development of reactor materials was unnecessary, obsolete, and almost economically impossible.

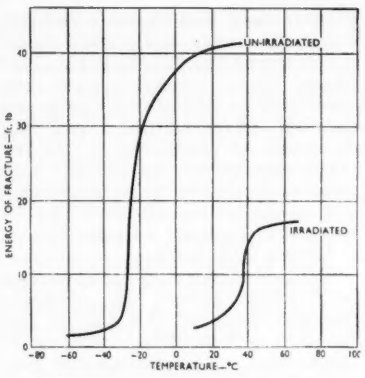


Fig. 3.—Effect on the transition temperature of En.2 steel of neutron irradiation of 1.9×10^{19} n/cm².
(Churchman, Mogford and Cottrell).

THE INSTITUTION OF ELECTRICAL ENGINEERS

The Application of Irradiation in Industry. By M. C. Crowley-Milling, M.A. (Metropolitan-Vickers Electrical Co., Ltd.).

Although the value of irradiation processes was demonstrated more than five years ago, radiation techniques have been developed, costs can be economic, very few industrial installations exist. These were the author's conclusions to an exceedingly comprehensive and well-documented paper on the subject. The reasons, in his opinion, for this small number, include the reluctance of industrial organizations to incur the capital cost of plant—until someone else has tried it on a large scale; the fact that really high-power machines have not been available for very long; the probability that legislative changes may be required before irradiation is applied to food and drugs; the fear that new chemical processes may be discovered which might render irradiation unnecessary; the unrealistic statements made from time to time about the low cost and availability "in the near future" of large isotope sources.

The paper aims to give a brief engineering approach to the special problems of industrial irradiation. It commences by reviewing types of radiation, and points out that only γ rays and fast electrons are worth consideration, as neutrons may produce undesirable radioactive isotopes. After a

short section on dose units and activity, the paper reviews applications, dividing them roughly into two classes—the changing of molecular structure, such as cross-polymerization, vulcanization, and other chemical effects, and the elimination of some unwanted impurity without affecting the general properties of the material. Into this second class fall sterilization of food and drugs, disinfestation, and the prevention of sprouting in potatoes and onions, etc. Probably more money is being spent on food sterilization (largely due to the U.S. Army) than on any other application.

Food can be effectively sterilized, it is pointed out, with doses of 2-5 megarads but unacceptable changes of taste occur. Improved keeping qualities, without complete sterilization, can be obtained with lower doses, of the order of 50,000-500,000 rads. Irradiation with low-energy electrons, which do not penetrate deeply, may be helpful in reducing the growth of moulds on fruit, without appreciably affecting the taste.

TABLE 1. Electron Accelerators Available

Type	Maker	Electron energy	Mean power	Approximate price of accelerator	Approximate cost per kW
		MeV	kW		
Resonant transformer	A	1	4.5	$69,000	£5,400
		2	10	$120,000	£4,300
		3.5			
Van de Graaff	B	1	0.25	$40,000	£57,000
		1.5	2.5	$50,000	£7,100
		2	0.5	$73,000	£52,000
		3	3	$130,000	£15,500
Linear accelerator	B	6.5	4	$194,000	£17,400
		9.5	4	$224,000	£20,000
	C	6	4	$145,000	£13,000
	D	6	5	—	—
		10	5	—	—
		20	2.5	—	—
	E	4	0.8	£30,000	£37,500
	F	4	1	£30,000	£30,000
		5	5	£50,000	£10,000
		10	10	£90,000	£9,000

TABLE 2. Estimates for Food-Irradiator Schemes

Source	Gross power	Effective dose rate	Hold up of material	Capital cost per gross kW	Cost of irradiation per megarad/lb	Notes
	kW	rad/min	tons	$\$\times10^3$	cents	
Fuel elements	4.9	4×10^2	22	92	0.82	Fuel elements free. No transport charges.
Gaseous fission products	50	5×10^2	17.5	13	0.14	Assuming suitable reactor available.
Coolant loop. Sodium 24	24	1.5×10^3	28	29	0.26	Assuming free use of suitable reactor.
Circulating indium solution	73	1.1×10^4	12	40	0.56	Special reactor. Neglecting cost of fuel.
Caesium 137	22.6	3.5×10^3	12	17	0.15	Neglecting cost of caesium 137.
Accelerator No. 1	7.5	$>10^4$	Negligible	55	0.22	Including all equipment.
Accelerator No. 2	50	$>10^4$	Negligible	20	0.09	Including all equipment.

On production of radiation, the paper describes several methods for fast electrons; the resonant transformer, the Van de Graaff, and the microwave linear accelerator, and gives some idea of comparative costs, the author's figures being reproduced in Table 1.

It is pointed out that although Van de Graaff machines have been built up to 8MeV, the reliable commercial limit of operation seems to be about 3MeV. Linear accelerators, on the other hand, may be much larger, the largest one at present constructed being 25 MeV, with a power of 30 kW.

Methods of producing γ rays are reviewed, and, ironically, the "free" method (used fuel elements from a reactor) turns out to be the dearest one in the long run, since the energy in the rods is small (due to self-absorption) and short-lived. Caesium-137 is suitable, but the annual production does not amount to more than a few thousand curies and, if it rose to 10^7 curies by 1965, this would represent a gross power of under 40 kW. Cobalt-60 is even more suitable, but its high costs and low availability are against it. Table 2 shows estimates for an irradiation scheme, taken from a report published by the Quartermaster's division of the U.S. Army. Although the power is quite high, it is pointed out that the dose rates are very low, and that cross-linking of polythene, for example, would take over a month, with the fuel-element scheme.

Many other aspects of the problem are dealt with at some length, including the questions of penetration efficiencies, dose measurement, shielding, heating effects and the practical application, including methods of beam spreading and splitting, to irradiate both sides simultaneously, the general design of chambers and conveyor systems, and the economics of irradiation. A list is given of industrial installations, including those available for rental.

THE INSTITUTION OF CHEMICAL ENGINEERS
(in association with the B.N.E.C.)

The Second Uranium Plant at Springfields. By R. C. Alexander, M.I.Mech.E., L. P. Shortis, M.A., B.Sc., and C. J. Turner, C.B.E., B.Sc., M.I.Mech.E.

The completion of the second uranium plant at Springfields represents a major expansion of capacity. The paper gives a review of the significant improvement in methods of processing, and a general description of the plant.* It also makes clear the position of the establishment in respect to Windscale, from which it receives depleted uranyl nitrate from the processing of irradiated fuel elements, and Capenhurst, to which it sends uranium hexafluoride for enrichment by the diffusion process, receiving the enriched hex. back for re-processing to enriched uranium. An outline is given of a proposed process for directly calcining concentrates to UO_3, reducing to UO_2, hydrofluorinating to UF_4, and fluorinating to UF_6, each stage providing a measure of purification, the final low-volatile metallic impurities being removed as fluorides, by distillation.

The processing of Uranium Ore Concentrates and Recycle Residues to Purified Uranyl Nitrate Solution at Springfields. By H. Page, B.Sc., Ph.D., L. P. Shortis, M.A., B.Sc., and J. A. Dukes, A.R.I.C.

This paper describes in some detail the first portion of the Springfields cycle, i.e., the dissolving, filtration, and purification processes. An interesting point regarding the dissolving stage is the variation in nitric acid requirements with concentrates of different origins and compositions; South African (72%U) requiring but 0.54 (te/teU), whilst Rum Jungle (45%U) requires 1.8 te, and the Congo mineral ore anything from 1-3 te.

Possibly the most interesting portion, however, is the account of the development of the filtration plant. Early experimental work proved that with filtration direct on the cloth, the rate was impossibly low, and the method adopted utilized a precoat of filter aid (diatomaceous earth) supported on a stainless steel (150-mesh) drum, and a considerable amount of work was carried out on the rate of advance of the scraper blade, and the washing of soluble uranium from the filter cake, for which atomizing water sprays were eventually selected.

The Fluidized Solids Dryway Process for the Production of Uranium Tetrafluoride at Springfields. By E. Hawthorn, F.R.I.C., A.M.C.T., L. P. Shortis, M.A. B.Sc., and J. E. Lloyd, B.Sc., A.R.I.C.

This paper deals in more detail with the later processes; i.e., starting with the uranyl nitrate, with the object of producing the uranium tetrafluoride, without the intermediate stage of ammonium diuranate. An account is given of the difficulties encountered, and their solution. Apparently, the continuous process has not yet been realized, although confidence is expressed in the future possibilities.

The Use of Hydrogen as a Reactor Coolant. By D. Bradley (U.K. AEA, Harwell).

This contribution is not intended to establish the feasibility of hydrogen cooling, but to highlight some of the problems which will be encountered in such an investigation which, to be conclusive, would have to refer to a particular case. The well-known engineering advantages of hydrogen from the

* A description of Springfields Works as it was in January, 1959 will be found in *Nuclear Engineering* for March, 1959.

heat transfer and pumping power aspects are offset by other handicaps, such as compatibility with fuel elements, with graphite, and with the steel structure, on account of the formation of pyrophoric hydrides, methane, and decarburization, respectively. This of course, takes no account of the explosion hazards traditionally associated with hydrogen. All these problems can be overcome, but it would be essential to be able to guarantee purity greater than 95% at all times, otherwise it would be necessary to consider explosion-proof construction—not, in the author's opinion, a practicable solution. Additional plant would also be necessary, for the manufacture of hydrogen on site, and for air purging.

Pumping Studies on Aqueous Thoria Slurries. By R. Murdoch and H. A. Kearsey (U.K. AEA, Harwell).

This paper was of highly specialized interest, and gives results obtained in pumping slurry through horizontal and vertical loops to determine its behaviour under various conditions of rate of flow, pipe diameter, particle size, and state of flow (i.e., laminar or turbulent).

THE INSTITUTE OF MARINE ENGINEERS (Joint Panel on Nuclear Marine Propulsion).

Some Aspects of Marine Reactor Safety. By K. Maddocks, B.Sc.(Tech.), A.M.C.T., M.I.Mar.E.

Studies in the field of marine propulsion, as the author remarks, fall into two fields —safety and economics. Pointing out that the U.S. "Savannah" was due for completion in 1960, the paper emphasizes the urgency of the safety considerations now under review in many quarters.

Roughly speaking, the ground covered by the paper can be divided into two parts. First, there is the general problem of safety, as particularly applied to marine reactors, which mainly resolves into matters of shielding and containment, although many other aspects of safe reactor operation are dealt with, including the integrity of fuel elements. Methods of calculation are suggested, although the author draws attention to the present limitations of accuracy of shielding calculations, and says that it must be recognized that the characteristics of any reactor have never yet been ascertained in detail until full-scale tests are carried out.

It is suggested that any scheme of refuelling would be more acceptable to the appropriate authorities if at least single-skin containment could be maintained, and a system of airlocks is proposed. The additional mechanical complications would, it is felt, be outweighed by the advantage of ensuring that the primary circuit—particularly any defective fuel elements—was never open to the atmosphere near the ship.

The second part of the paper is devoted to hazards peculiar to marine installations. Apart from the normal rolling and pitching, there are many others which are not immediately obvious, including shock, fire, and stranding. This last, by possible sudden removal of the "heat sink" surrounding the vessel, might raise problems of heat disposal, even under shut-down conditions.

Actual sinking is considered under two headings. In comparatively shallow waters, it is assumed that salvage operations would be possible, since divers would be shielded by water, and it is assumed that salvage could be completed within twelve months, thus setting a time limit for corrosion of fuel elements. Deep-sea sinking, on the other hand, does not cause concern. Although hydrostatic pressures might cause collapse of the system, and release of fission products, the high degree of dispersion should prevent significant accumulation of activity away from the vicinity of the wreck. He felt that the unrestricted entry of a nuclear-propelled vessel into ports throughout the world must await the establishment of confidence, which could only follow several years of successful operation.

Research Reports

IGR-TN/W-319. Coolant Gags for the Calder Reactor. By J. T. Wilson and M. Long (R. and D., Windscale).

Investigations on the relationship between gag size and pressure drop for the three sizes of Calder channel, over a range of flow rates. In the original work at Harwell, results were given in the "equivalent length" form; i.e., the length of slug channel having the same pressure drop as the gagging section. These results may vary with the Reynolds number and, due to the long range of results (some 100-1) curves are so steep that it is difficult to detect points not lying on the curves. A preferred method is to evaluate the number of velocity heads lost on entry, for each gag, and the results are presented in this form. The authors point out that gagging will not be as accurate as was anticipated, since it is possible for variations of the seating of the gags in their support bosses to give errors in results, these being more noticeable for the larger gags.

A.E.R.E.-R2970. Studies of the Toxicology of Plutonium. By Katharine Williams. (H.M.S.O., 4s.)

Concise but comprehensive survey of the subject, commencing with history and organization of research, and proceeding via questions of absorption, toxicity, organ deposition, bone studies, retention and pathological effects in other organs, maximum permissible body burden and maximum values permissible in air and water, to a very full list of references.

A.E.R.E. C/R1450. The Oxidation of Graphite during Irradiation in Oxygen. By P. C. Davidge, M. Tomlinson and J. Wright. (H.M.S.O., 11s.)

An account of experimental work carried out to measure, rapidly, very low rates of CO_2 evolution from graphite samples irradiated in BEPO at 2×10^{13} n/cm² sec in a stream of oxygen, at temperatures from 60°C-300°C. It was known that the oxidation due to irradiation was much larger than that due to thermal action alone (at least one order of magnitude) and it was also discovered that this was obtained at the higher temperatures in the absence of radiation on previously irradiated graphite samples. At lower temperatures, thermal oxidation rates were negligible—even with previously irradiated graphite—compared with radiation damage.

A.E.R.E.-Bib 120. Pumps and Electromagnetic Flowmeters for Liquid Metals. (H.M.S.O., 4s. 6d.)

A revised edition, superseding A.E.R.E. Inf/Bib 93 giving a list of unclassified literature on the subject. Mechanical pumps are now included as well as the electromagnetic type. More than 150 sources of information, including books, journals and A.E.R.E. reports are listed and indexed.

A.E.R.E. Med/R2854. The Natural History of Beryllium Disease. By Katharine Williams. (H.M.S.O., 5s. 6d.)

Although beryllium was first discovered in 1798, its toxic effects were not recognized until the 1930s, and not really taken seriously until considerably later; although the author points out that in no other case of occupational toxicity has there been such prompt recognition and preventive action taken. It would appear that the diagnosis has been made more difficult by the lapse of time (up to several years) which can occur between the last exposure and the onset of clinically active disease.

In addition to the historical survey, the report discusses the correlation of the incidence of the disease with atmospheric pollution, and the derivation tentative maximum allowable concentrations in working atmospheres. It also discusses the medical aspects of beryllium disease, in both acute and chronic forms. An extensive bibliography of work in this field is contained.

MEETINGS

January 5-7.—The Institution of Mechanical Engineers, Symposium on Recent Mechanical Engineering Developments in Automatic Control (1 Birdcage Walk, Westminster, London, S.W.1, 5 p.m.).

January 13.—Women's Engineering Society, London Branch ("Hope House," 45 Gt. Peter Street, Westminster, S.W.1, 6.30 p.m.). "Health Physics and Nuclear Power," B. C. Godbold.

January 20.—I. O. Welding, N.L. Branch (54 Princes Gate, S.W.7, 7.30 p.m.). "Further Developments in the Welding of Atomic Plant," A. Prince.

January 20.—The Institute of Physics, Education Branch (The Institute's House, 47 Belgrave Square, London, S.W.1, 6 p.m.), "Health Physics," H. J. Dunster.

January 21.—The Institute of Metals, Birmingham Local Section (College of Technology, Gosta Green, Birmingham, 6.30 p.m.), "Physical Methods of Analysis," K. M. Bills.

January 26.—The Institution of Engineers and Shipbuilders in Scotland (39 Elmbank Crescent, Glasgow, C.2, 6.30 p.m.), "Some Aspects of Marine Reactor Safety." K. Maddocks.

January 26.—The Institute of Marine Engineers (The Memorial Building, 76 Mark Lane, London, E.C.3, 5.30 p.m.), "Control and Instrumentation of Marine Reactors," R. Anscomb and F. Hutber.

January 27.—The Institution of Engineers and Shipbuilders in Scotland (joint meeting with Dundee Institute of Engineers, University College, Dundee, 7.15 p.m.), "Marine Nuclear Propulsion—a recent survey," K. Maddocks.

January 29.—Non-Destructive Testing Society (Reid Knox Hall, Brit. Inst. of Radiology, 32 Welbeck Street, London, W.1, 7 p.m.), discussion on how best to merge all interests in non-destructive testing.

BERYLLIUM

A Review of Industrial Development in the U.K.

BECAUSE of the attractive nuclear properties of beryllium the metal is receiving intensive development in the United Kingdom by the U.K. AEA, the contracting consortia and the tube and raw material manufacturers. Its application as a fuel canning metal, for advanced gas-cooled reactors particularly, is dependent upon the successful production of uniform tubes of adequate purity and ductility.

Consolidated Beryllium

Consolidated Beryllium Ltd. was formed in July, 1959, by Imperial Smelting Corporation Ltd. and the Beryllium Corporation of U.S.A. for the manufacture of beryllium metal and its alloys. A plant has been constructed at Avonmouth, near Bristol, and is producing nuclear grade metal in cob and ingot form; plans for the manufacture of beryllium powder are also in hand. Whilst at one time the electrolytic process was expected to yield the purest metal further development has led the company to adopt the magnesium reduction process.

Magnesium Reduction Process*

THE process for the production of beryllium metal adopted by Consolidated Beryllium is based upon the reduction of beryllium fluoride with magnesium. Principal stages are, first, the production of ammonium fluoberyllate from beryllium hydroxide, then conversion to the fluoride, reduction with magnesium, leaching of the slag to recover cob metal, vacuum melting, machining of the ingots to swarf and, finally, recovery of beryllium from recirculated slag.

In the first stage, beryllium hydroxide as a filter cake containing about 57% BeO is dissolved in aqueous ammonium bifluoride to produce ammonium fluoberyllate according to the equation:

$$Be(OH)_2 + 2\,NH_4HF_2 = (NH_4)_2BeF_4 + 2\,H_2O$$

This reaction is carried out in Keebush vessels fitted with steam heaters and stirrers. A batch of beryllium hydroxide is added to recycled mother liquor at about 90°C. Ammonium bifluoride solution is then added to the vessel until the slurry clears at a pH value of 6.8. After cooling to 70°C the solution is filtered to remove silica and some iron.

The liquor is concentrated by evaporation and run off into a crystallizer, where it is cooled to room temperature. Crystals are filtered off in a vacuum filter and mother liquor is returned to storage for recycling. The ammonium fluoberyllate crystals containing between 2 and 3% water are transferred to a steam-heated paddle drier from which they are discharged into sealed hopper containers.

Ammonium fluoberyllate decomposes readily on heating into beryllium fluoride (m.p. 793°C) and ammonium fluoride vapour:

$$(NH_4)_2BeF_4 = BeF_2 + 2\,NH_4F$$

This decomposition is carried out in an induction-heated graphite crucible. Ammonium fluoride evolved in this process is withdrawn into a water scrubber and recovered as a concentrated solution. The beryllium fluoride is tapped from the furnace at a temperature of about 850°C into graphite moulds in the form of sticks which are then broken up and transferred into sealed hopper containers.

The reduction of beryllium fluoride by magnesium is carried out in a completely sealed graphite crucible. Crushed beryllium fluoride and chopped magnesium ingot are heated together to a temperature of about 1,350°C, when beryllium metal (m.p. 1,283°C) separates from the molten slag in the form of small beads which rise to the surface. The mixture of slag and metal is then cast into sticks in a graphite mould.

The next stage is leaching of the slag to separate cob metal. The mixture of slag and cob metal is transferred in sealed containers to a rubber-lined leaching barrel where flux is dissolved and metal liberated into a slurry of magnesium fluoride crystals. Metal is recovered on screens and the magnesium fluoride crystals and beryllium fluoride solution are recycled. Cob metal recovered at this stage requires several washings to ensure an effective slag separation, after which it is vacuum dried. It still contains about 1% magnesium and small quantities of halide fluxes which are removed by vacuum melting. The cob metal is melted *in vacuo* in a beryllia crucible at a temperature of about 1,300°C and cast into graphite moulds.

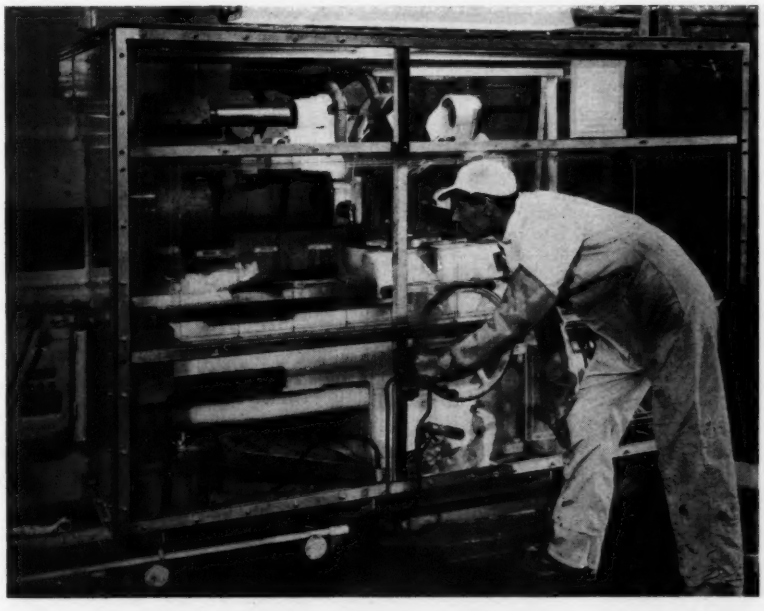
When ingot metal is required for direct fabrication the outer layers are machined off to give a smooth surface. When powder is required, the whole of the ingot is reduced to chippings in an enclosed and ventilated lathe.

The chippings are drawn from the tip of the tool by a vacuum line and collected into sealed containers ready for milling to powder. Offcuts from ingot are returned to the process for vacuum melting.

Beryllium containing liquors from the slag leaching stage and other recycle materials are purified in a circuit similar to that used for beryllium hydroxide dissolving. Ammonia and hydrofluoric acid are added to reconvert the solution to ammonium fluoberyllate.

Ingot metal can be obtained with a purity of 99.4-99.7% Be. Powdered metal is slightly less pure due to oxidation.

Ingots of beryllium are reduced to chips on this swarfing lathe at I.C.I.'s Witton plant. All operations are remote-controlled.



* By S. W. K. Morgan (B.Sc., A.R.S.M., A.M.I.M.E.), Research Director.

Imperial Chemical Industries

A BERYLLIUM plant, for the production of wrought products, has recently been commissioned at the I.C.I. Metals Division in Birmingham. Costing £1 million the plant is part of a £10 million programme for the development of new metals. Most of this programme has included the establishing of plants to produce titanium and zirconium, but research is also being undertaken on the new metals, niobium, hafnium and vanadium.

Operating as a research production unit, the beryllium production plant will have an initial output of about 7 tons per annum with maximum capacity of 10 tons. It is housed in a single-storey building and employs 200 workers.

Owing to the toxic effect of beryllium considerable safety precautions have been taken and the plant has been divided into contact areas, where the material is handled, and non-contact areas. There are no windows and the air is constantly filtered, heated and exchanged. More than 3,000 samples are taken weekly to determine the concentration of beryllium, and the maximum permissible level is 0.01 μg per 100 cubic metres of air. All personnel are required to wear special clothing and, in some cases, air-suits. Additional precautions include the machining inside glove boxes from which air is automatically withdrawn.

Present production includes fuel element cladding for the AEA for use in the AGR and associated experiments. Few technical figures are available of this production, however, but it is known that the AEA are supplying the raw material. World price for beryllium is £20/lb and the price of the wrought products is about £160/lb. The raw material used is flake and pebble beryllium and the first process is one of purification by melting in a high vacuum furnace. The material is then cast into solid ingots which are chipped and ball-mill ground into a fine powder (200 mesh). The swarf is packed into graphite moulds and sintered at high temperatures (about 1,290°F) under vacuum, and the consolidated material is then machined into sizes suitable for extrusion. This powdering process is necessary as even the vacuum-cast beryllium has a very large grain size and is still extremely brittle.

In the extruding stage the slugs are silver-plated to provide protection and lubrication, but the plating is removed after extrusion. Pressure furnaces are used for preheating and the extruding of tubes and rods is done in vertical presses.

The material is cut to length, straightened and annealed in the finishing stage. Inspection is carried out by water pressure and then non-destructive testing with an eddy current, intro-view inspection instrument. The finished products are washed in detergent and water before final inspection.

Ingots of zirconium weighing half a ton are in production at the Metals Division and fuel element cans are produced both for home and foreign consumption, particularly the Scandinavian countries. As yet, only an extensive research programme is being carried out in connection with hafnium, niobium and vanadium.

Tube Investments

At Walsall the TI Research and Development Division has established laboratories for the small-scale production of beryllium tubes and for the investigation and development of manipulation processes. Whereas the Walsall establishment is provided with full facilities for the handling of the exposed metal, the hot drawing of the billet is undertaken by the Chesterfield Tube Co., the metal having been previously clad and completely contained in steel. This same company—a subsidiary of TI—has recently signed a "know-how" agreement with the Superior Tube Co. of Morristown, U.S.A., on the manufacture of beryllium products, and agreement has been reached on the co-ordination of their future development programmes.

TI has already received contracts from the U.K. AEA, France and the U.S.A. for beryllium tubes to the value of around £250,000. It will shortly be bringing into operation at Walsall new extensions to the laboratories which will enlarge the facilities available for machining and processing. TI's annual output at present is in the region of ½ ton which implies a throughput of raw material (at present brought in from the U.S.) of several times this figure.

Considerable progress has been made in the past few years on tube production, exemplified by the delivery to the U.K. AEA of 50 tubes similar in diameter to those scheduled for AGR use and each 5 ft long. Circumferential ductility of the finished product is small but not zero. It has been found that in the warm (400-450°C) drawing of hollows, a reduction of 20 : 1 can be tolerated, metallographic examination showing that although the basal planes are orientated in the direction of extrusion the radial orientation is random. Greater reduction results in some preferred radial orientation with consequent high brittle characteristics. For reductions of less than 20 : 1 the circumferential ductility whilst less than the value that can be measured by conventional techniques (1-2%) is demonstrated by the ability to perform post-extrusion manipulation. Changes in diameter of several per cent can be made without destroying the integrity of the tube—a matter of considerable significance where high dimensional precision of the finished product is required. AGR-type tubes have also been cold bent to a radius of 5 in.

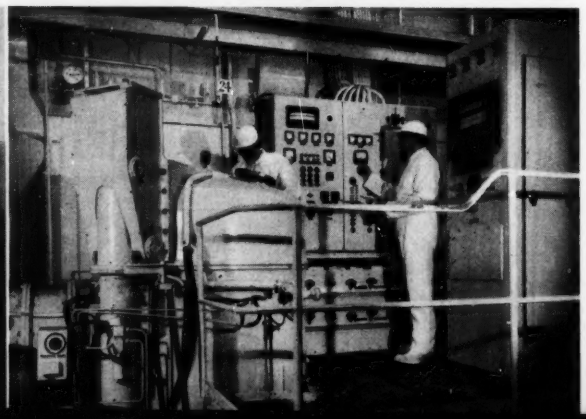
Price of the finished tubes is dependent upon the wall thickness and length required and can vary from £100-£400 per pound. The upper figure will refer to wall thicknesses of the order of 0.010 in. which have been successfully made, whereas wall-thicknesses of 0.030 in. (quoted for AGR at the Geneva conference, *Nuclear Engineering*, Oct., 1958) lead to a cost in the region of £150/lb.

Murex

As agents acting on behalf of the AEA, Murex Ltd., have designed and built an experimental beryllium metal plant at Milford Haven, based on the chlorination process. Capacity is in the region of 1 ton of metal a year. At present beryllium compounds are being supplied to the AEA. Associated with beryllium production Murex have a ceramic unit making such items as crucibles and moderator bricks from beryllia.

AEA

In addition to negotiating development contracts the AEA is undertaking a considerable amount of research itself. A pilot beryllium metal production plant has been installed at Springfields.



(Below, left) The control laboratory at the I.C.I. plant where the raw material and metal is tested for purity by analysis and radiography. (Below, right) The sintering furnace where the beryllium powder is treated before extrusion.

TRANSLATIONS

Résumés of Principal Articles

Le Réacteur Auto-Régénérateur Rapide de Dounreay est Devenu Critique (page 5)

Le réacteur auto-régénérateur rapide de la Grande-Bretagne à Dounreay est devenu critique pour la première fois le 14 Novembre. Une contribution d'une membre du personnel explique pourquoi la mise en opération de ce réacteur nouveau genre a été retardée. Un examen très sévère eut lieu tout au cours du programme de mise en service qui dura près d'un an. Les bouteilles et l'équipement d'enlèvement furent vérifiés deux fois—à l'air et dans le réfrigérant de métal liquide. L'article décrit aussi le remplissage du circuit de réfrigérant, son opération initiale et le chargement du combustible.

Considérations sur le Contrôle pour le Brûlage Elevé (page 10)

A mesure que le brûlage de combustible augmente le coefficient de température de réactivité passe du négatif au positif, par suite de l'accumulation de plutonium 239; cela porte atteinte à la stabilité du réacteur. Les constantes de temps y sont démontrées être longues. Les changements de puissance de réacteur entraînent des changements de concentration en xénon, qui peuvent devenir oscillatoires. Avec de gros noyaux de réacteurs, des instabilités tant axiales que radiales peuvent se produire, bien que les premières soient improbables; un contrôle en zones fera en sorte que l'action corrective nécessaire soit prise.

Réacteurs pour la Propulsion des Navires (page 14)

La Conférence de Hambourg sur la Propulsion Nucléaire des Navires organisée par Studiengesellschaft zur Förderung der Kernenergie-Verwertung in Schiffbau und Schiffahrt e.V. a eu lieu du 25 au 28 Novembre, et 750 délégués représentant 14 nations y assistèrent; 36 mémoires y furent soumis. Le thème central de la conférence a été la proposition de construire un navire nucléaire pour servir aux études, en convertissant un bateau-citerne déjà construit de 16.000 tonnes. Deux auteurs, F. E. Faris et W. Haubold respectivement (tous les deux membres de l'Interatom, les fournisseurs éventuels d'un réacteur OMR pour le groupe propulseur développant une puissance sur l'arbre de 12.000 C.V.) décrivirent en détail les diverses caractéristiques de conception du groupe et discutèrent la chimie du réfrigérant employé, le Santowax-R. Deux autres mémoires d'un intérêt particulier furent contribués par H. P. Kinsey et H. W. Bowker (U.K. AEA) et W. A. Hepburn et E. H. Specht (Administration Maritime du Département de Commerce des E.U.). Les deux ont traité des mérites comparés des types de réacteurs refroidis au gaz, à eau pressurisée, à eau bouillante et organiques modérés dans la propulsion des navires, le premier présentant un projet de bateau-citerne de 65.000 tonnes poids mort et un groupe propulseur développant une puissance sur l'arbre de 22.000 C.V., et le dernier étudiant un groupe propulseur développant une puissance sur l'arbre de 30.000 C.V. L'étude de l'A.E.A. tire la conclusion que le type de réacteur modéré organique présente les plus grandes possibilités et le mémoire américain soumet la proposition que le système refroidi au gaz (hélium), allié à une turbine à gaz pourra offrir les plus grands avantages lorsque les expériences actuelles se seront transformées en une réalité pratique dans une dizaine d'années, par exemple.

El Reactor Autoregenerador Rapido de Dounreay Entra en Periodo Critico (pág. 5)

El Reactor autoregenerador rápido británico instalado en Dounreay, entró en período crítico por vez primera el 14 de noviembre. En un artículo preparado por uno de los miembros del personal se explica la razón en la demora de la puesta en servicio de este novel reactor. Se hizo un meticuloso examen durante todo el programa de puesta en servicio que duró casi un año, se hizo una doble comprobación de las matraces y equipo de retirada tanto al aire como en el refrigerante de metal líquido, El artículo describe también el llenado del circuito del refrigerante, su funcionamiento inicial y la carga del combustible.

Consideraciones de Control Para Consumo Elevado (pág. 10)

Con progresivo aumento de consumo de combustible, el coeficiente de temperatura de reactividad cambio de negativo a positivo, debido a la acumulación de plutonio 239; esto afecta la estabilidad del reactor. Los constantes de tiempo se muestran como largos. Los cambios en energía del reactor conducen a cambios en concentración de xenón, que pueden volverse oscilatorios. Con grandes núcleos de reactor, pueden surgir instabilidades tanto axiales como radiales, aunque la primera es improbable; el control por zonas asegurará que se tome la necesaria acción correctora.

Reactores Para Propulsion Maritima (pág. 14)

La Conferencia celebrada en Hamburgo sobre Propulsión Nuclear Marítima organizada por Studiengesellschaft zur Foerderung der Kernenergieverwertung in Schiffbau und Schiffahrt e.V duró desde el 25 al 28 de noviembre, con asistencia de 750 delegados representando 14 naciones, y se discutieron 36 documentos. El tema central de la conferencia fué la propuesta para construir un buque nuclear para fines de investigación, convirtiendo un buque cisterna ya construido de 16.000 toneladas para este fin. Dos autores F.E. Faris y W. Haubold respectivamente (ambos miembros de Interatom, suministradores potenciales de un Reactor OMR para la unidad propulsora dando 12.000 H.P.) al árbol describieron en detalle los varios diseños y características de la unidad y discutieron la composición química del refrigerante empleado, Santowax–R. Otros dos documentos de especial interés fueron presentados por H.P. Kinsey y H.W. Bowker (de U.K. AEA) y W.A. Hepburn y E.H. Specht (Administración Marítima del Departamento de Comercio de Estados Unidos de Norte América).

Ambos se relacionaron con los méritos relativos de tipos de reactores enfriados a gas, agua a presurizada, agua hirviente y orgánicos moderados para la propulsion de buques, el primero de ellos relacionado con un buque cisterna de 65.000 toneladas peso muerto y una unidad propulsaora de 22.000 H.P. al árbol y el segundo para una unidad propulsora de 30.000 H.P. al árbol.

El estudio realizado por AEA llega a la conclusión que el reactor tipo moderador orgánico ofrece las mejores posibilidades y el documento de los Estados Unidos señala que el sistema de enfriado a gas (helio) acoplado a una turbina de gas pudiera presentar las mayores ventajas cuando los actuales experimentos cristalicen en un diseño práctico en unos 10 años, por ejemplo.

Dounreay FR kritisch (Seite 5)

Englands schneller Brutreaktor in Dounreay wurde das erste Mal am 14ten November kritisch. Der Beitrag von einem Mitgliede des Stabes bringt die Erklärung dafür, warum die Auftragserteilung für diesen neuen Reaktor sich verzögert hatte. Strengste Prüfungen erfolgten während der ganzen Dauer der Aufstellung des Auftragsprogramms, die beinahe ein Jahr anhielten. Gefässe und Versatzeinrichtungen wurden doppelt geprüft—in Luft und in flüssigem Metall, das als Kühlmittel benutzt wird. Der Aufsatz beschreibt ferner das Füllen der Kühlmittel-Umläufe, die anfängliche Inbetriebnahme und die Einführung des Brennstoffs.

Ueberlegungen hinsichtlich der Kontrolle bei hoher Spaltstoff-Ausnutzung (Seite 10)

Variationen in den Brennstoff-und Moderator-Temperaturen führen in einem Kraftwerk-Reaktor zu einem Wechsel der Reaktivität in allen Teilen des Kernes. Wenn die Leistung von einer einzuhaltenden Höhe zu einer anderen geändert werden soll, dann haben die Temperaturänderungen innerhalb des Kerns eine bestimmte Wirkung auf die Reaktivität, der durch Kontrollstab-Verschiebung entgegengewirkt werden muss. Obwohl gegenwärtig die britischen Kraftwerk-Reaktoren mit einer stetigen Leistungs-Abgabe arbeiten, müssen die zukünftigen Reaktoren, die wesentlich grösser sein werden, mit variierender Leistungs-Abgabe betrieben werden können. Der Aufsatz diskutiert einige der Kontroll-Probleme, die unter solchen Bedingungen auftauchen, um hohe Spaltstoff-Ausnützung zu erreichen.

Reaktoren zum Antrieb von Schiffen (Seite 14)

Die Konferenz über Schiffsantrieb durch Kernenergie, die von der Studiengesellschaft zur Förderung der Kernenergieverwertung in Schiffbau und Schiffahrt e.V. organisiert war, fand vom 25ten bis zum 28ten November statt und war von 750 Delegierten besucht, die 14 Nationen repräsentierten; 36 Vorträge wurden gehalten. Das zentrale Thema der Konferenz war der Bau eines Atom-Schiffes für Forschungszwecke durch Umbau eines vorhandenen Tankers von 16.000 t. Zwei Vortragende, F. E. Faris und W. Haubold (beide sind Mitglieder der "Interatom," die als Lieferant des OMR-Reaktors für die Antriebs-Maschinerie von 12.000 Wellen PS in Frage kommt) beschrieben im Einzelnen die verschiedenen Kennzeichen des Entwurfs der Anlage und besprachen die chemischen Eigenschaften des zu benutzenden Kühlmittels: Santowax-R. Zwei andere Vorträge von besonderem Interesse waren von H. P. Kinsey und H. W. Bowker (U.K. AEA) und von W. A. Hepburn und E. H. Specht (Maritime Administration des Department of Commerce der Vereinigten Staaten). Beide behandelten die vergleichsweisen Vorzüge von gasgekühlten, Presswasser-, Siedewasser- und mit organischen Moderatoren arbeitenden Reaktortypen für Schiffsantriebe, wobei die ersteren einen Plan besprachen für einen Tanker von 65.000 t und einer Antriebsanlage von 22.000 Wellen-PS, und die letzteren für eine Antriebsanlage von 30.000 Wellen-PS. Die AEA Studie kommt zu dem Ergebnis, dass der Reaktor Typ mit organischem Moderator die grösste Aussicht hat, während die amerikanische Untersuchung zu dem Schluss kommt, dass das gas-gekühlte (Helium) System in Verbindung mit einer Gas-Turbine die grössten Vorteile bieten könnte.

TRANSLATIONS—Résumés of Principal Articles (Contd.)

Soudure par Faisceau d'Electrons. Comparaison avec la Méthode Argonarc (page 19)

Une comparaison est établie entre l'emploi d'un faisceau d'électrons sous vide avec des méthodes plus usuelles pour la soudure de matériaux difficiles. L'avantage principal consiste dans l'élimination de toute contamination atmosphérique, mais d'autres avantages sont représentés par l'absence d'électro-décontamination et le fait que la méthode à faisceau d'électrons a des possibilités pour l'assemblage des céramiques et même des semi-conducteurs. Il est aussi possible, en arrivant à une plus forte concentration de faisceau, de souder des profils plus épais tout en réduisant la zone chauffée au minimum. Il y a aussi certains avantages économiques dûs à l'élimination des gaz inertes.

On y donne une brève description de l'équipement qui a été mis au point en Grande-Bretagne. Le développement original a vu sa naissance en France.

Graisses qui Résistent aux Radiations (page 23)

Cet article traite de l'épreuve de rendement des graisses dans les paliers roulants dans l'emploi pour les réacteurs et décrit des essais faits dans des conditions en et hors pile. Il a été démontré qu'il est possible de fabriquer des graisses dont le fonctionnement sera satisfaisant à des températures élevées en présence de CO_2 à la dose de $2{,}7\times10^{18} n/cm^2$ par comparaison aux graisses traditionnelles dont on ne peut s'attendre à ce qu'elles ne résistent que 15 à 20% de cette dose même à une température réduite.

Soldadura Por Haz de Electrones. Comparacion con el Metodo Argonarc (pág. 19)

Se establece la comparación entre el empleo de un haz de electrones al vacío con sistemas más convencionales de soldadura de materiales difíciles. La ventaja principal consiste en la eliminación de toda contaminación atmosférica pero hay otras tales como la ausencia de electro-descontaminación y el hecho que el método de haz de electrones ofrece posibilidades para la unión de cerámica y hasta de semiconductores. También se hace posible, al establecer una más alta concentración del haz, soldar secciones más gruesas a la par que se reduce la zona calentada al mínimo. También hay ciertas ventajas económicas debido a la eliminación de gases inertes.

Se presenta una breve descripción del equipo que ha sido evolucionado en la Gran Bretaña. La idea original proviene de Francia.

Grasas Resistentes a la Radiacion (pág. 23)

Este artículo se refiere a los resultados de las pruebas de grasas en cojinetes de rodillos en condiciones de reactor y describe las pruebas realizadas tanto fuera de la pila como en la pila misma. Se ha comprobado que las grasas pueden ser preparadas para operar satisfactoriamente a elevadas temperaturas en presencia de CO_2 al dosaje de 2.7×10^{18} n/cm^2 en contra de lo logrado con grasas corrientes de las que solamente se puede esperar que resistan alrededor del 15/20% de esta dosis aun a temperaturas reducidas.

Schweissen mit Elektronenstrahlung. Vergleich mit der Argon-Lichtbogen Methode (Seite 19)

Die Verwendung eines Elektronenstrahls im Vakuum wird mit den mehr konventionellen Schweissmethoden für schwierige Werkstoffe verglichen. Der Hauptvorteil liegt in der Eliminierung jeder Vergiftung der Atmosphäre, jedoch sind weitere Vorteile die Abwesenheit von Vorrichtungen zu elektrischer Entgiftung und die Tatsache, dass die Elektronenstrahl-Methode die Möglichkeit gibt keramische Körper und sogar Semikonduktoren zu schweissen. Es ist sogar möglich durch Erreichung hoher Strahlen-Konzentration dickere Querschnitte bei gleichzeitiger äusserster Verkleinerung der erhitzten Zone zu schweissen. Es sind weiter gewisse wirtschaftliche Vorteile zu verzeichnen wegen der Ausschaltung der Edelgase.

Schmierfette unempfindlich gegen Bestrahlung (Seite 23)

Der Aufsatz befasst sich mit der Prüfung von Schmierfetten für Rollenlager im Betriebe unter Bedingungen, wie sie im Reaktor vorhanden sind, und beschreibt Prüfungen, sowohl ausserhalb des Meilers, als auch innerhalb des Meilers. Es hat sich gezeigt, dass Fette hergestellt werden können, die zufriedenstellend bei erhöhter Temperatur in Gegenwart von CO_2 bis zu einer Strahlungshöhe von $2{,}7\times10^{18} n/cm^2$ arbeiten können gegenüber den konventionellen Schmierfetten, von denen man höchstens erwarten kann, dass sie etwa 15–20% dieser Strahlung aushalten, selbst wenn die Temperatur reduziert wird.

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Catalogues

An illustrated summary of the **U.K. AEA's** annual report for 1958-9 is now available from Government Bookshops.

An attractive brochure outlining the general activities of the **Power-Gas Group** has been produced. (Stockton-on-Tees.)

A new Product Specification (E) P99-8, describing the **Bailey** pneumatic relay for use in automatic control schemes, is now available. (Purley Way, Croydon.)

The October issue of the *EFCO Journal* contains an article on stress relieving in the No. 1 reactor vessel at Berkeley. (Electric Resistance Furnace, 161 Queens Rd., Weybridge, Surrey.)

No. 7 issue of *Prospects* contains an article on the use of **Acheson MoS/2** as a dry film lubricant on remote handling equipment at Harwell. (Acheson Colloids, 70 Hill Street, Richmond.)

Controls for Radiation have produced brochures on advanced film badge dosimetry and bio-chemical analysis for hazard controls. (Cambridge, Mass., U.S.A.).

Information sheets on **Jessop-Saville's** forging and casting alloys for high-temperature applications are now available. (Brightside Works, Sheffield.)

An article on the preparation of heavy water by catalytic exchange is contained in the October issue of *Platinum Metals Review*. (Johnson, Matthey, Hatton Garden, London, E.C.1.)

Three recent publications by **English Electric** concern geared steam turbo-generating sets, squirrel-cage induction motors and induction motors. (Marconi House, Strand, London, W.C.2.)

A leaflet describing a new range of electrical connectors, terminal clamps and lugs has been produced by **D. J. Equipment (Hersham).** (43 Queens Road, Hersham, Walton-on-Thames.)

A report by a committee of inquiry on the exhibition facilities in the U.K. is now available. **(Federation of British Industries,** 21 Tothill Street, London, S.W.1.)

Wiggin Nickel Alloys have produced an attractive brochure of the uses of their alloys. (Wiggin St., Birmingham.)

A publication illustrating their activities in pipework fabrication has been released by **Charlton, Weedle.** (Manor Works, Newcastle-on-Tyne.)

The first of a series of five booklets, *I.C.I. Titanium (1) Wrought Products*, is now available. (I.C.I., Millbank, London, S.W.1.)

Knitmesh have produced a new brochure on their electronic shields. (36 Victoria St., London, S.W.1.)

The multivane fans, type MVAZ, of **Sturtevant Engineering** are listed in a new publication. (Southern House, Cannon St., London, E.C.4.)

Keith Blackman's centrifugal fans, blowers and exhausters are listed in a new publication. (Mill Mead Rd., London, N.17.)

A section on particle accelerators is included in the No. 7 edition of *Copper*. **(Copper Development Association,** 55 South Audley St., London, W.1.)

The August edition of the **Metropolitan-Vickers** *Gazette* contains an article on some engineering aspects of ZETA and one on a 25 MeV linear accelerator. (Trafford Park, Manchester.)

AEA Courses in 1960

AEA courses during 1960 will be held on the following dates:—

Jan. 4-12: Standard course on reactor technique No. 20. Harwell Reactor School.

Jan. 11-Feb. 5: General isotope course, No. 59, Wantage Isotope School.

Feb. 8-19: Special course for water chemists, Isotope School.

March 7-April 1: General isotope course, No. 60, Isotope School.

April 17-29: Standard course on reactor technique, No. 20 (part two), Reactor School.

April 26-29: Course for directors and senior executives, Isotope School.

May 2-3: Course on advanced chemistry, Isotope School.

May 16-June 2: Medical course, Isotope School.

June 20-July 15: General isotope course, No. 61, Isotope School.

July 18-22: Course on autoradiography, Isotope School.

Aug. 29-Sept. 9: Course on radioisotope methods in analytical chemistry, Isotope School.

Sept. 12-16: Course on radiological protection, Isotope School.

Sept. 20-23: Course for senior directors and executives (D.C.7), Isotope School.

Sept. 26-Oct. 7: Course on advanced biochemistry, Isotope School.

Sept. 29-Oct. 7: Standard course on reactor technique, No. 21(A), Reactor School.

Oct. 12-Dec. 16: Standard course on reactor technique, No. 21(B), Reactor School.

Oct. 17-Nov. 11: General isotope course, No. 62, Isotope School.

Nov. 21-Dec. 16: General isotope course, No. 63, Isotope School.

World News

Members of the Euratom Commission at Harwell during their recent visit to the U.K. Mr. W. F. Wood, deputy chief engineer, reactor operations, explains the workings of PLUTO to M. E. Hirsch with M. E. M. Sassen (left) and Lord Plowden (right).

International

THE SUPPLY TRANSACTION under which Japan will receive three tons of natural uranium at $35.50 kg from the IAEA (who in turn obtained it, free of charge, from Canada) has been completed.

LARGEST PROTON SYNCHROTRON in the world, the CERN 25 GeV machine, began operating on November 25 at the headquarters in Geneva. It has cost £10 million. The Council of the organization has recently approved the budget of Swiss F 65 million for this year and it has been announced that international scientific co-operation in high energy accelerator research will be increased.

NEW IAEA SCHEME for assistance, administered by the Exchange Unit, provides for visits by specialists, the exchange of personnel, the organization of training courses, research and special grants for studies at post-doctorate levels.

RADIOISOTOPE TRAINING will be given by the IAEA to students from Asia and South America. The Agency recently took delivery at ORNL of a mobile radioisotope laboratory, a gift from the U.S.A. The unit will tour Mexico first and then the Argentine.

A MEETING to review the work in progress in Euratom countries was held in Brussels on December 15. One of the objects was to enable the Commission to plan future work in order to avoid duplication.

United Kingdom

THIRD REACTOR at Chapelcross came into full operation on December 7. Total supply of electricity from the station to the national grid is now over 100 MW. The last reactor is due to go critical by the end of March next year.

MAXIMUM NUMBER of members of the AEA will be increased from a chairman and 10, to a chairman and 15. The number of people employed by the AEA has risen from 17,000 to 37,000 since 1954.

COLLABORATION in the study of controlled thermo-nuclear reactions for peaceful purposes, has been announced, following the first meeting of the U.K.-Euratom Continuing Committee. A comparison of programmes and an exchange of personnel have been decided upon as the best means of achieving this. The Committee also considered suggestions for co-operation in the fast breeder field and advanced gas-cooled reactor system, and a preliminary technical meeting will be held this month to discuss how this plan can be implemented.

NESTOR will be the name of the AEA's latest reactor to be installed at Winfrith by Hawker Siddeley Nuclear Power. Based on JASON design it will be modified for continuous operation at a power of up to 10 kW and the layout has been altered so that it can act as a neutron source for five experimental assemblies simultaneously. A thermal neutron flux of 10^{11} neutrons, cm^2/sec in the centre of the core and of up to 10^8 n/cm^2, sec in typical assemblies is planned.

NO SETTLEMENT has been reached following a meeting of the General Purposes Committee of the National Joint Industrial Council of the AEA to discuss a wage increase for industrial workers. Negotiations will continue.

DRAGON PROJECT graphite symposium held in Bournemouth during November was attended by 90 scientists and engineers from Government organizations and private firms in 10 European countries. Object of the symposium was to discuss and review the characteristics, the development and the production of special graphites for use in high temperature reactors, and to exchange knowledge on methods of making such graphites impermeable.

Canada

URANIUM EXPORTS during October showed a drop in value of $2.3 million over September, 1959, and were $5.9 million less than for the same period during 1958. The value of exports for the first 10 months of 1959 was $40.3 million higher than for the same period in 1958, reflecting the achievement of peak production early in 1959.

HALF-WAY MARK has been reached in the construction on the 20-MW heavy water moderated, natural uranium fuelled prototype power station NPD-2, according to AECL. The $32 million station is expected to go critical mid-1961.

After nearly two years work at Hinkley Point power station, the shells of the two reactors are complete.

Sir John Cockroft starting JASON, the Hawker Siddeley research reactor on November 24. Mr. B. Emmerson, supervisor of the reactor is on his right.

Canada

MINING AND MILLING operations by Quebec Lithium are reported to have been temporarily suspended. This has resulted in a stockpiling of spodumene concentrate, sufficient to produce about 1,000 tons of lithium carbonate. Lithium Corporation of the U.S.A. have recently refused to accept further shipments of the concentrate.

France

A CONSORTIUM, called Sud-Atome, interested mainly in nuclear-propulsion for ships, has been formed in France. The companies are, Chantiers et Ateliers de la Ciotàt, Forges et Chantiers de la Méditerrannee, Chantiers et Ateliers de Provence and the Société Provinciale de Construction Navales, and two engineering companies, Industriel des Ateliers Terrin and the Société d'Installations Thermiques et Auxiliaires des Machines.

FULL SPECIFIED CAPACITY of 1MW has now been reached by the water cooled, enriched uranium reactor, Melusine, at Grenoble, after a trial period of operation lasting five months.

East Germany

CO-OPERATION AGREEMENTS have been signed with Rumania for nuclear research.

West Germany

THE BUDGET ALLOWANCE for the Federal Ministry for Nuclear Power has been increased threefold to DM 16.7 million during 1960. In addition, the Government's contribution towards the construction of an electron-synchrotron in Hamburg will be increased from DM 5.2 million to DM 21 million.

Italy

WET STEAM COOLING research will be undertaken by the CISE (Information Study and Experimentation Centre) for Euratom. The $600,000 programme is within the framework of the U.S.-Euratom agreement and will be directed at using wet steam as a coolant in reactors moderated by water. It is expected that the programme will lead to the developing of a reactor prototype in Italy.

FINAL RATIFICATION by the Italian Parliament is needed before the nuclear research centre at Ispra becomes a Euratom establishment. Workers at the centre have recently tabled a motion to the Government requesting a decision as soon as possible.

Japan

OFFICIAL APPROVAL has been given by the Government for the building of G.E.C.'s 150-MW nuclear power station at Tokai near Tokyo. Work is expected to start immediately and the power station should be commissioned some time in 1964.

Netherlands

FOREIGN AFFAIRS minister, Mnr. J. M. A. H. Luns, has confirmed that Holland may sign an agreement with Euratom for the research reactor at Petten to be used for Euratom projects.

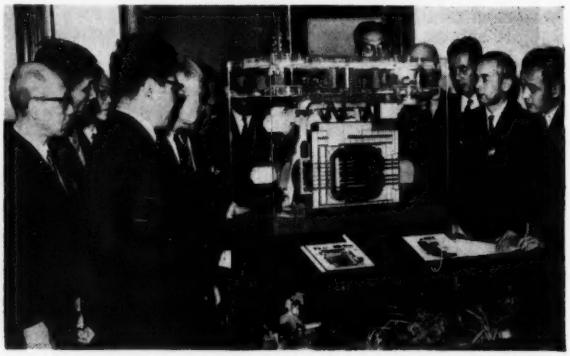
New Zealand

A 3MeV ACCELERATOR is to be ordered from the U.S.A. for the Institute of Nuclear Physics. Costing about £30,000 the accelerator will be installed at Gracefield near Wellington.

A REQUEST has been received from the IAEA for two foreign scientists to study in New Zealand Government departments.

Norway

TOP PRIORITY RATING has been given to a Government report for research on nuclear merchant ships and has been passed to the Storting by the Cabinet.



Members of the Japanese Nuclear Ship Mission who are engaged on a survey of the present situation, and future direction, of nuclear ship propulsion, on a visit to the Atomic Energy Division of G.E.C. at Erith. The Mission were shown a model of the G.E.C. gas-cooled reactor unit for ship propulsion.

SECOND FUEL CHARGE for OEEC's Halden, boiling heavy water reactor, has been ordered from Swedish Atomenergi. Costing $500,000 the charge will consist of approximately 1,500 kg of 1.5% enriched uranium oxide made up into 100 7-element assemblies of Zircaloy-clad rods. Delivery will be in March, 1961 and will include eight extra fuel assemblies minus uranium, for experimental use. A power of 20 MW is expected from the second charge.

BRITISH MADE control apparatus, known as a reactor transfer function analyser, has recently been installed in the OEEC reactor at Halden. The equipment will enable the reactivity of the reactor to be sinusodially modulated over a range of frequencies from 10 c/s to 0.002 c/s and will measure the phase and amplitude of the resulting neutron flux response to within 1° and 1% respectively. It will be used to obtain data on the physics and dynamic behaviour of the reactor.

South Africa

NUCLEAR RESEARCH in South Africa will be concentrated on uranium development, according to Dr. Roux, head of the Atomic Energy Board. In face of growing competition for the world uranium markets Dr. Roux has said that improved methods of mining and extracting should be investigated.

A COMMISSION to inquire into the danger of ionizing radiation is to be set up by the Government.

THE ADMINISTRATOR of the Cape Province has announced that £100,000, in annual instalments of £20,000, will be given towards the establishing of a nuclear research centre near Cape Town. The institute will be run jointly by the Universities of Cape Town and Stellenbosch.

Spain

A URANIUM ORE processing plant, capable of treating 200 tons of ore daily, has come into operation at Andujar in Andalusia. A total capacity of 500 tons daily is expected to be reached at a later date.

Switzerland

A TECHNICAL EVALUATION of the safety aspects of the Diorit reactor project has been carried out by a team from the IAEA at the request of the Government. The project is a 12.5 MW research and materials testing reactor, heavy-water moderated and cooled, using natural uranium fuel.

Turkey

FOUNDATION STONE for the nuclear research centre at Lake Kucuk Cekmece, 15 miles from Istanbul, has been laid. A I-MW pool-type reactor, supplied by American Machine and Foundry, will be housed in the centre and is expected to start operating early in 1962.

U.S.S.R.

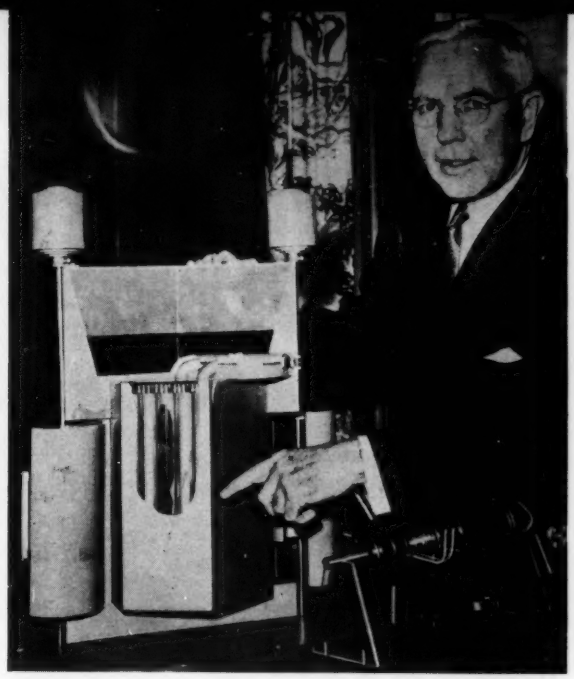
NUCLEAR SUBMARINES are, according to *Jane's Fighting Ships*, under construction in the Soviet Union. The submarines are reputed to be 3,000 tons (same as *Dreadnought*) and 328 ft in length. No information as to what type of reactor is being used is available.

U.S.A.

ADDITIONAL URANIUM STATISTICS for the period 1948 to 1959 have been made available by the AEC. Domestic ore reserves are now estimated to be 88,900,000 tons. Average cost of production is $10.14/lb and since 1948 the AEC have purchased uranium concentrate to the value of $888 million from domestic sources. In 1958 more than $156 million was the total investment in uranium processing plants.

NEW OFFICE at the AEC will assist the General Manager in the fields of licensing and regulation, and health and safety.

AIR COOLING APPARATUS for nuclear-powered submarines will be produced by the Carrier Corporation following the awarding of a $3 million contract by the Bureau of Ships. The machines will operate on the vapour-absorption principle using reactor-produced steam.



Mr. J. McCone, chairman of the U.S. AEC, demonstrating a full-scale model of the lightweight reactor which has been designed to supply power for instruments in space vehicles. The reactor is expected to operate for about a year.

Two technicians removing a plug from the Argonne Fast Source Reactor which recently began operating at Idaho Falls.

CONSTRUCTION is expected to begin early next year on a new metals and ceramics facility for the Metallurgy Division of the Oak Ridge National Laboratory. The project is estimated to cost $6.5 million and will consist of two main buildings.

EXTENSIVE MODIFICATION is to be carried out to the General Electric Vallecitos Boiling Water Reactor (VBWR). This includes internal natural circulation, forced circulation with variable speed pumps and dual-cycle facilities; the ability to operate a small core with characteristics of a large power reactor using UO_2 fuel; control system capable of providing long fuel irradiations and considerable instrumentation in the core for testing core designs and core performances.

CRITICALITY has been achieved in the Argonne Fast Source Reactor facility at the National Reactor Testing Station, Idaho Falls. Initial criticality was achieved with 21.28 kg of uranium-235 in the air-cooled $125,000 experiment.

SELECTED as a basis for contract negotiations, is a proposal by The Lummus Company for a 20-MW high-flux research reactor using uranium-aluminium-alloy fuel plates with heavy-water moderator, coolant and reflector. The reactor is expected to cost $10 million.

A LIGHTWEIGHT high-temperature reactor (220 lb), SNAP intended for space-vehicle auxiliary power has been successfully operated in land tests. The system entails the transferring of heat from the reactor by liquid sodium coolant to a boiler containing mercury. The mercury vapour is then directed into a miniature turbine.

FUEL ELEMENTS for the Elk River 22-MW BWR, to be built by Allis-Chalmers, will be manufactured by the Nuclear Division of The Martin Company. 148 bundles of 25 stainless-steel tubes containing ceramic pellets of uranium oxide and thorium oxide will form the fuel system.

CONTAINING more than 10 miles of 1-in. stainless-steel tubes, the first heat exchanger for the Con Edison nuclear power station has recently been delivered to the site on the Hudson River. Weighing 60 tons, the exchanger is 40 ft long and 13 ft wide. It is one of four to be supplied by Babcock and Wilcox for the 275-MW pressurized water reactor.

A NEW LICENCE has been issued to Commonwealth Edison enabling them to bring the Dresden boiling water, heterogeneous-type reactor up to a power level of 315 MW(t) which represents 50% of its rated power. The reactor went critical on September 28.

FLOW TESTS on fuel elements for General Electric's plutonium recycle test reactor (PRTR) facility at Hanford have begun. This first PRTR element is 8 ft 4 in. long and weighs 150 lb. It is a 19-rod cluster system with Zircaloy-2 clad elements containing 6¼ lb of un-enriched uranium dioxide powder. Of 85 fuel elements for the first reactor loading, 25 will contain plutonium in the form of plutonium-aluminium alloy.

THREE VERSATILE FACILITIES will be added at the Argonne National Laboratory. Two will be critical assemblies, Zero Power Reactor 6 and Zero Power Reactor 9, and the third will be a low-flux, special-purpose neutron source reactor. It will be light-water moderated and cooled using highly enriched uranium fuel and is to be called "Juggernaut."

THREE ACCELERATORS have been bought by the AEC from High Voltage Engineering. They will be 12-MeV positive-ion accelerators and will be housed at the Argonne, Oak Ridge and Rice Institute laboratories. Total cost is $3,333,510 and delivery is expected to be accomplished within 18 months.

RECENT CONSTRUCTION PERMIT licences issued by AEC include: University of Missouri for a 10-kW swimming-pool-type research reactor; Stanford University for a 10-kW swimming-pool-type and Worcester Polytechnic for a 1-kW swimming-pool type.

Personal

Mr. A. J. Young.

Mr. G. B. R. Feilden.

Mr. R. E. Burnett.

Mr. R. J. Horlock.

Appointments

Mr. G. B. R. Feilden to the Board of Hawker Siddeley Industries.

Mr. T. B. Ellis as secretary of G.E.C.

Sir Frank Lee as permanent secretary to the Board of Trade.

Dr. S. C. Curran of AWRE as principal of the Royal College of Science and Technology, Glasgow.

Mr. R. E. Burnett to the board and managing director of Marconi Instruments.

Dr. G. Macfarlane as deputy director of the National Physical Laboratory.

Mr. A. J. Young to the board and managing director of English Electric Valve.

Mr. N. C. Macdiarmid to the board of Stewarts and Lloyds.

Admiral Sir Michael M. Denny to the board of English Steel Corporation. **Mr. W. D. Pugh** as chairman of: English Steel Forge and Engineering, English Steel Rolling Mills, English Steel Castings, English Steel Spring and Taylor Brothers; **Mr. W. E. A. Redfearn** as managing director of English Steel Forge and Engineering; **Mr. R. G. H. Taylor** as chairman of English Steel Export and **Mr. G. Graven** as managing director. Further English Steel Forge and Engineering appointments are: **Mr. R. W. Brocklehurst** as general superintendent, **Mr. E. Levesley** as superintendent of the forge machine shops and **Mr. R. J. H. Hunt** as superintendent of heavy forge.

Mr. D. A. Smith as managing director of Weir Valves.

Mr. L. J. Thomas as managing director of S. E. Opperman.

Mr. R. Summers, chairman of John Summers as the president of the British Iron and Steel Federation.

Sir Leslie Rowan as chairman of Robert Boby, a Vickers subsidiary.

Mr. N. H. Jones to the board of Rio Tinto Mining of Central Africa and associated companies.

Mr. A. I. Baker as president of the British Engineers' Association.

Mr. H. P. Forder and **Mr. A. R. Hay** to the board of the United Steel Companies.

Mr. H. Morley to the board of Samuel Fox.

The Institute of Metals appointments are: President, **Sir Ronald Prain;** vice-presidents, **Mr. H. M. Finniston** and **Mr. H. W. Hignett;** ordinary members of the council, **Mr. R. W. K. Honeycombe, Mr. I. Jenkins, Mr. E. Robson, Mr. J. Salter** and **Mr. C. Smith.**

Mr. D. E. Greenaway and **Mr. W. J. Bonner** to the board of High Precision Equipment.

Sir Owen Wansbrough-Jones to the board of British Oxygen.

Overseas :

Mr. C. N. Watson-Munro, chief scientist at the Australian Atomic Energy Commission to the chair of thermo-nuclear physics at Sydney University.

Mr. Chaerul Saleh as deputy chairman of the Indonesian Atomic Energy Council.

Mr. R. J. Horlock as manager of John Thompson's new branch office in the Argentine.

CERN appointments are: President, **Mr. F. de Rose;** vice-presidents **Prof. W. Heisenberg** and **Mr. J. Willems;** chairman, finance committee, **Mr. J. H. Bannier;** scientific policy committee member, **Prof. F. Perrin.**

U.S.AEC appointments are: **Mr. M. B. Kratzer** as deputy director, division of international affairs; **Brig. Gen. I. L. Branch** as assistant director for aircraft reactors; **Mr. J. R. Moore** as director of the new office of contract policy.

Mr. J. H. Rubin as liaison officer for the Canadian-U.S. exchange of information on heavy water power stations.

Dr. S. G. English as chairman of the newly formed committee to advise the U.S.AEC on the investigation of peaceful uses of nuclear explosives.

Awards :

Dr. G. T. Seaborg the U.S.AEC's Enrico Fermi Award for 1959.

Resignations :

Mr. J. C. George has resigned from the board of Joy-Sullivan on his appointment as parliamentary secretary to the Minister of Fuel and Power.

Mr. T. P. Everett from the boards of Richardsons Westgarth, Richardsons Westgarth (Hartlepool) and Richardsons Westgarth Atomic.

Retirement :

Mr. L. Clarke as chairman of L. Clarke, while still retaining a seat on the board.

Obituary :

Nuclear Engineering regrets to announce the death of the following:

Prof. C. T. R. Wilson on November 15 at the age of 90.

1960 Conferences and Symposia

February 3-5: Western Industrial Isotope Conference, U.S.AEC, University of California.

February 10-11: Gas-cooled reactor symposium, American Nuclear Society, Delaware section, Philadelphia.

March 2-4: Colloquium on low and medium energy nuclear physics, Société Française de Physique, Grenoble.

March 19: Symposium on direct conversion of nuclear energy, American Nuclear Society, Pittsburgh section, Pittsburgh.

April 3-8: 6th Nuclear Congress, 6th Nuclear Engineering Conference, 8th Atomic Energy Conference and 6th International Atomic Exhibition, New York.

April 19-22: International symposium on the metallurgy of plutonium, Société Française de Métallurgie, Grenoble.

April 27-29: Second European symposium on chemical reaction engineering—section on non-conventional reactors, European Federation of Chemical Engineering, Amsterdam.

May 3-6: Symposium on fuel-element fabrication, IAEA, Vienna.

June 23-July 3: First plenary session of ISO/TC/85 on nuclear energy and concurrent sessions of subcommittees 1, 2, 3, and 4, General Secretariat of the International Organization for Standardization, Geneva.

June 5-9: World power conference, International Executive Council of World Power Conference, Madrid.

June 12-16: Sixth annual meeting of the American Nuclear Society, Chicago.

June 15-29: 7th International nuclear congress and exhibition on electronics and atomic energy, National Italian Committee for Nuclear Research, Rome.

August 9-12: Symposium on inelastic scattering of neutrons in solids and liquids, IAEA, Vienna.

August 25-Sept. 3: 10th International Conference on high energy nuclear physics, International Union of Pure and Applied Physics, Rochester, New York.

August 29-Sept. 3: International Conference on nuclear structure, Atomic Energy of Canada, Queen's University, Kingston, Ontario.

Aug.-Sept.: Conference on medium and small power reactors, IAEA, Vienna.

Aug.-Sept.: Conference on radioisotopes in physical sciences and industry, IAEA, Vienna.

Sept. 20-Oct. 7: IAEA fourth general conference, Vienna.

November: Symposium on nuclear ship propulsion, IAEA (location undecided).

Nov.-Dec.: Symposium on experimental and test reactors, IAEA, Vienna.

December 12-14: Winter meeting of American Nuclear Society, San Francisco, California.

Industrial Notes

Bruce Peebles have been awarded a £100,000 contract by **Atomic Power Constructors** for a special low frequency supply for motors to wind main control rods in the reactor core of the Trawsfyndd power station.

Taylor, Taylor and Hobson will use their micro-alignment telescope to measure the graphite distortion in the Calder Hall reactors. The telescope has been used extensively in the construction of nuclear power stations.

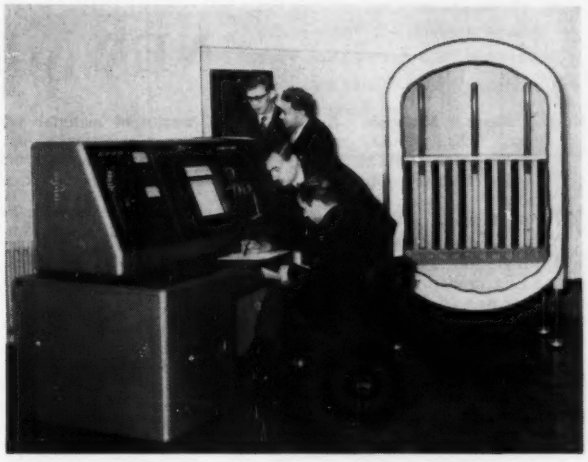
G.E.C. are to supply a power-operated manipulator for the new nuclear research laboratories being constructed for the **CEGB** at Berkeley. The manipulator will form part of the handling equipment for the examination of irradiated fuel elements.

The **AEA** have selected the **Plessey** burst slug detection scheme for the AGR at Windscale. The system is based upon a square matrix arrangement of the fuel sampling pipes in that 16 X co-ordinate detectors and 16 Y co-ordinate detectors are used to give continuous monitoring of the 253 fuel channels, without sequential gas sampling. Eight detector units are housed in one pressure vessel making a total number of four similar assemblies for the complete installation. Output signals from each detector are processed by transistorized ratemeters, using printed circuits, and the data are shown in the control room on four eight-point recorders of conventional design.

Mullard Equipment are to supply the U.S.S.R. with a 4-million volt linear accelerator designed for X-ray treatment of deep-seated tumours. This company have now built 10 linear accelerators, four for scientific research purposes, five for medical use and one for industrial radiography.

Hellermann compression terminals for interconnecting and cubicle wiring from 1/.036 to 7/.029 and equivalent conductor sizes are to be used by the CEGB on nuclear, generation and transmission work.

Elliott-Automation are negotiating with **Manufacture de Machines Du Haut-Rhine** for the manufacture of their automation equipment in France.



The Vickers-Armstrongs reactor training simulator and reactor core in operation.

Following a world-wide market survey, the South Marston Works of **Vickers-Armstrongs (Aircraft)** have introduced a range of low-cost reactor simulators: they are primarily intended to supplement lectures on reactor kinetics, to train potential operators or to stage reactor experimental programmes. The Mk. 1 has a power range of up to 100 kW and costs £3,100. A working core model representing a graphite moderated reactor for use in conjunction with the simulator costs £900. The Mk. 2, priced at £4,120, is a more elaborate equipment with a power range of up to 10 MW. Finally, the Mk. 3 can be tailor-made to customer's requirements at a basic cost in the region of £12,000.

A.E.I. have announced the change of names of several famous companies. Metropolitan-Vickers Electrical now become A.E.I. (Manchester), British Thomson-Houston become A.E.I. (Rugby) and Siemens Edison Swan will be called A.E.I. (Woolwich). Five new product divisions are also announced, bringing the total to 14. They are: Instrumentation division which combines the interest of Sunvic Controls with the instrument and meter, X-ray and scientific apparatus departments of Metropolitan-Vickers; cable division; construction division; telecommunications division and radio and electronic components division.

The wiring and connectors division of **Plesseys** will now be responsible for the production of the Modac connector range.

Electrical Remote Control have introduced, through their subsidiary, **Equipment Services,** a quick delivery service for electrical timing and control equipment, of either standard or specified manufacture.

H. J. Enthoven and Sons have signed an agreement with **Edlow Lead** of Ohio, U.S.A., for the exclusive rights to patents and know-how for the production of shipping casks for irradiated fuel elements, lead bricks and other types of radiation shielding, disposal containers for radioactive waste and isotope containers.

The **A.W.R.E.** metals division will have a beryllium display at the **Engineering Materials and Design Exhibition** at Earls Court from February 22-26. The show will include a large number of products in beryllium including cast, sintered, fabricated and machined pieces.

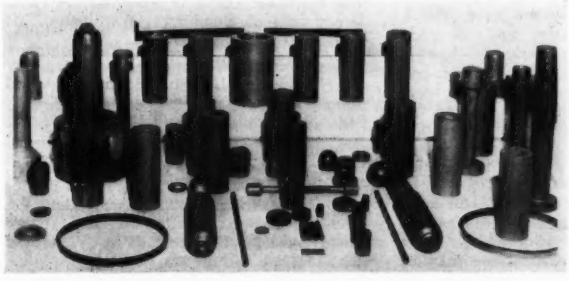
Avo Limited are to supply 140 Radiac survey meters for radiation monitoring to the Defence Dept., Eire.

Powell Duffryn Engineering have acquired the whole of the share capital of **Pipeweld Limited,** a contracting company at Paston Road, Wythenshawe, Manchester.

A series of Christmas lectures on nuclear energy will be given by Dr. T. E. Allibone of **A.E.I.** at the **Royal Institution,** 21 Albemarle Street, London, W.1, on December 29, 31 and January 2, 5, 7, 9.

Specialized activities in nuclear engineering are regularly covered in journals associated with *Nuclear Engineering* and published by **Temple Press Limited.** On December 18, *The Aeroplane and Astronautics* carried a four-page article "Progress in Nuclear Powered Aircraft" by J. Burkett. In effect, the author summarizes the world's literature on the subject. In so doing he presents a very clear picture of the progress made so far and the potentialities of nuclear propulsion in the air. Such factors as the choice of reactor, special design requirements and the difficulties of incorporating the necessary shielding in an airframe are discussed: 33 references are given as the source of information.

Overseas readers will find frequent references to British nuclear engineering developments in another Temple Press journal, *The Overseas Engineer*, which is published monthly. Nuclear propulsion for ships is dealt with from the ship-building angle in another monthly, *The Motor Ship*. Further details of Temple Press publications can be obtained direct from the publishers at Bowling Green Lane, London, E.C.1.



A display of Hawker Siddeley Nuclear Power graphite impregnated specimens. The furfyl alcohol process was used to reduce the permeability to gases at high temperatures.

NEW BOOKS

Nuclear Reactor Materials. By B. R. T. Frost, B.Sc., Ph.D., and M. B. Waldron, B.Sc., Ph.D., A.I.M. (No. 7 of the *Nuclear Engineering* Monographs. 79 pp., 25 illus. Temple Press Limited, 12s. 6d. net.)

This, like the others in the series, is a book for students and those whose specialist interests lie primarily in other branches of nuclear work—i.e., those who require an overall survey of the field in an understandable form without delving too deeply into the extensive (and expensive) specialized literature on each aspect of the subject. Based on a series of lectures given by staff of the Metallurgy Division, AERE, Harwell, to students in the Department of Nuclear Engineering at Queen Mary College, the book opens with a consideration of theoretical metallurgy, including crystal structure, slip theory, and equilibrium diagrams. Structural materials, and their physical and nuclear properties, are followed by fuels, liquid metals and ceramic and metal-ceramic mixtures. The final chapter is devoted to corrosion and its many-sided effect on reactor design. The treatment throughout is as simple and straightforward as it is possible to make a comparatively short survey of a complex subject.

Progress in Nuclear Energy. Physics and Mathematics. Vol. III. Edited by D. J. Hughes, J. E. Sanders and J. Horowitz. (403 pp., Pergamon Press, Ltd., 105s.)

The 21 papers included in this volume are a selection from those presented at the second U.N. Conference on the Peaceful Uses of Atomic Energy held at Geneva in 1958. The papers have been chosen well to give the latest experimental techniques and data in the physics and mathematics of nuclear reactors. They therefore deal primarily with the interactions of neutrons with matter, in particular, with the thermalization, absorption and diffusion of neutrons, the mechanisms of the fission process, with aspects of neutron spectroscopy and with methods of determination of the interaction cross-sections of thermal, epithermal and fast neutrons, tabulated data on the values obtained and comparisons of these values available from recent American, European and Russian work. In this last connection, a useful index is given relating to 70 different nuclides of interest in reactor studies, with references to those pages in the text where neutron cross-section data is given. In view of the conflicting results obtained in previous work, this comparison is particularly valuable.

There is always the danger, when a book is made up from a selection of papers, that it has little continuity; indeed, in some cases, it is surprising that the compilation has been made at all. This is not the case in the present volume; though few readers will be able to study consecutively all the papers gathered here, and, indeed, will not usually want to do so, yet the selection and classification by these three authoritative editors of papers of particular importance and relevance to a given aspect of nuclear physics and engineering is of undoubted value. Not only is this book useful for those who have no access to the full Geneva reports or no time to read through the wealth of material available, it is also an expert selection of data directly of use to the research worker and designer concerned with nuclear reactor physics. J.Y.

Uranium Production Technology. Edited by C. H. Harrington and A. E. Ruehle. (579 pp. D. van Nostrand Co., Ltd., 131s. 6d.)

Uranium was the first metal required in a very high purity—the so-called "nuclear purity"—on a tonnage basis; its chemical reactivity increases the production problems enormously. The Mallinckrodt Chemical Works was deeply involved with the satisfactory solution of these problems, and this book, by the technical personnel of their Uranium Division, is correspondingly authoritative. Its value to the technological student, and as a reference book, should be considerable, the only comparable work being Grainger's much briefer "Uranium and Thorium."

The extensive operations carried out by Mallinckrodt, up to and including the extraction of the metal, are discussed in full. Alternative and subsequent operations by other organizations, e.g., fabrication, alloying, hexafluoride production and enrichment, are also adequately treated. The information is up to date (references up to 1958) and a special chapter is devoted to very recent work on a pilot plant or laboratory scale. The modern trend towards ceramic rather than metallic fuel elements has been recognized and to the technology of uranium dioxide as a stage in metal production a brief section on enriched oxide production for fuel elements has been added. The subjects of ceramic fabrication and sintering are only mentioned, however. In partial compensation the chemistry of the oxides is very fully discussed.

The avowed intention of the authors is to present the underlying principles of the technology without inessential detail. The basic chemistry is indeed presented with clarity in a separate chapter, and properly illustrated in the succeeding technological chapters. In addition, sufficient detail is given to provide an excellent picture of the plant requirements, control and test procedures, etc. Additions particularly interesting to the industrial metallurgist are the chapter on health hazards and precautions, and the costing sections in many of the chapters on established processes.

The slang terms and abbreviations inevitably associated with an established industrial process are used more widely than is necessary. "OK liquor" and "NG liquor" are understandable, if undesirable, but what is an "as is" pH? R.G.B.

An Introduction to Thermonuclear Research. By A. Simon. (182 pp., Pergamon Press, Ltd., 35s.)

This is a rewrite of lectures given at Oak Ridge National Laboratory and, as good lectures should be, is remarkably clear in exposition, fast in style, not too subtle, and with proper attribution for original ideas and work. Each argument is backed by, or deduced from, mathematical theory, which is not too difficult for an engineer to follow. Not many have to be creative in this field—which is right on the edge of knowledge—but there are many who want to understand the operations being carried on in the search for control of this latest source of potential energy. There may be major breaks-through during the next decade, and no one likes to be left behind on fundamentals; it is here that the author fills a gap.

He first reviews the world's requirements of energy, and sees that uranium can meet the need for a long time; he also shows that the reserve of thermonuclear energy in our water is almost incredible. A critical self-sustaining mass of deuterium is difficult, being about 200 miles in diameter, so that the problem remains with a machine in which a plasma is maintained; tentative answers have been tried in the Stellarator in the U.S. and Zeta in this country, though we know that in the latter the exact functioning is not clear.

The theoretical temperature requirement is 10^8 degrees K and only a magnetic field can control electrons and ions at the same time, and for a sufficient time. There is at once the problem of the ends of the magnetic field, and this has been met by the toroidal form of tube. The problem of drift, because of the non-perfect uniformity of the magnetic field across the area of the torus, leads to the twist of the Stellarator, which balances out the first order drift. A second order drift is to be balanced by sections with reversed curvature. There is also the question of instability, which is mitigated by a longitudinal magnetic field. Above all, there is the problem of injecting the ingredients, deuterium and tritium in equal proportions, which has led to a variety of mirror machines or magnetic bottles, in which charged particles tend to be reflected from higher-than-average magnetic fields. The lines of attack are against this instability and diffusion of the plasma.

The way of advance seems long and costly, but the prize is great. The author has indicated the progress to date and where the difficulties lie, and in the space at his disposal he has done exceedingly well.

L.E.C.H.

Books Received

Boiling Water Reactors. (A selected bibliography.) Compiled by J. M. Jacobs. Atomic Energy Commission, Oak Ridge, Tenn., U.S.A. (available from the Office of Technical Services, Department of Commerce, Washington, 25, D.C.). 48 pp. (TID-3088). Price $1.50.

Encyclopedic Dictionary of Electronics and Nuclear Engineering. (In preparation.) Editor: R. I. Sarbacher. 1,400 pp. Sir Isaac Pitman and Sons, Ltd., 39 Parker Street, W.C.2 (by arrangement with Prentice Hall International Inc.). Price £8 (pre-publication price £6 6s.).

D_2O-Moderated Power Reactors—A Symposium. AEC report, No. TID-7575, available from the Office of Technical Services, Department of Commerce, Washington, 25, D.C. 156 pp. Price $1.50.

Principles of Radiation Dosimetry. By G. N. White. 124 pp. John Wiley and Sons, Inc., New York; Chapman and Hall, Ltd., 37 Essex Street, London, W.C.2. 56s.

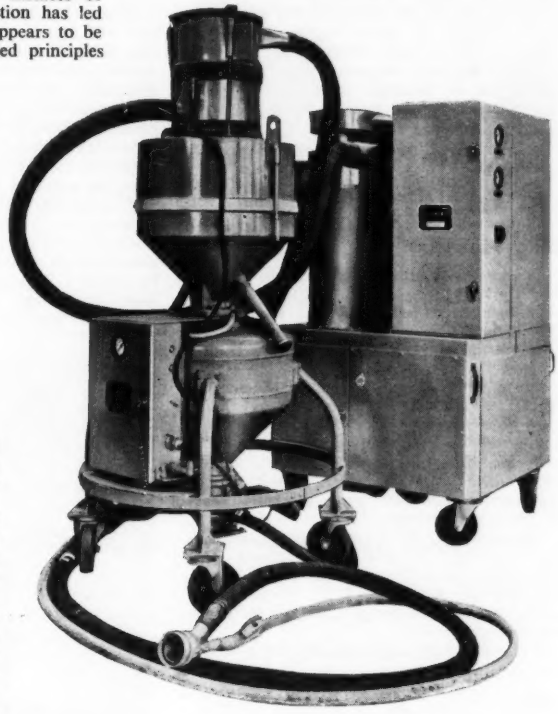
International Directory of Radio-Isotopes. Vol. 1. (Unprocessed and Processed Radio-Isotope Preparations and Special Radiation Sources). 263 pp. The International Atomic Energy Agency, Kaerntner Ring, Vienna, 1. 21s.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

"Open" Vacu-Blast for Clean Conditions

The general principles of Vacu-Blast equipment, in which complete recovery of both abrasive and dust is maintained during shot-blasting by means of combined blast and vacuum nozzles, are well known, and the plant range was first reviewed in *Nuclear Engineering* for September, 1956 (p. 261). Ideal in theory for the maintenance of absolutely clean conditions inside a reactor, (as opposed to wire brush cleaning, which raises difficult problems of dust removal) the necessity of maintaining true contact of the combined blast-vacuum gun on the interrupted surfaces of reactor internal construction has led to what, at first sight, appears to be a reversal of the accepted principles by the introduction of what is known as the "open" Vacu-Blast gear.



The Vacu-Blast Mk. II Major equipment.

It is well known that in shot-blasting, the dust presents the major problem. Unlike the shot, which rapidly settles due to its own weight, the dust is air-borne throughout the reactor, necessitating complicated "mopping-up" operations, as well as working conditions that are almost intolerable. The "open" design concentrates on dust recovery, providing a high vacuum around the blast nozzle to remove dust from the point of impact but allowing the abrasive to fall on the floor. Since intimate contact between the nozzle and the work is no longer essential, complex surfaces are as easily cleaned as with an open gun, without the attendant disadvantages of a working atmosphere that requires special clothing and breathing arrangements; a lightweight mask and rubber gloves being completely satisfactory.

The Mark II Major machine designed for this service has a large pressure hopper giving 30 min operation, if required, before the abrasive supply is spent. At the end of the blasting cycle, the shot is recovered by the vacuum pipe in the operating head and, before returning to the reservoir, is filtered, and all dust removed; the normal pick-up cycle being 15 min, after a 30 min blast. On the question of improved visibility and working conditions, it is interesting to note that a machine would change the entire air volume of a typical heat exchanger once per hour. By supplying air dried to below 70% relative humidity, the working surface will remain in the "as blasted" condition during the several days when cleaning is in progress.

Four Mk II Major machines are in use at Berkeley, and the method has also been adopted at Chapelcross and Bradwell.

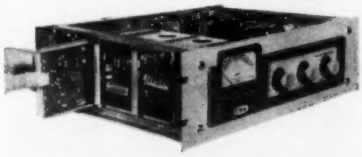
(*Vacu-Blast, Ltd., Wellcroft Road, Slough, Bucks.*)

1247

New Instrument Range

"Budget price" is the description given to a new range of I.D.L. instruments, of which three are already on the market. Known as the "1800" series, the range has been designed to give flexibility in application, and simplicity in maintenance. Cabinets have tilt-up stands, so that they can be used singly or stacked; rack mounting can also be used when required. Access can be obtained to the interior without disconnecting cables, and further simplification of the maintenance situation is ensured by the use of identical power packs in all types of instrument. Printed circuit, plug-in boards are used extensively throughout.

The first three, already available, are a scaler, a high-voltage supply, and an amplifier-selector. Further units in the range will include a ratemeter, potentiometer unit, and a pre-scaler.



I.D.L. Series 1800 amplifier-selector unit.

(*Isotope Developments, Ltd., Beenham Grange, Aldermaston Wharf, nr. Reading, Berks.*)

1248

Portable Contamination Monitor

A new E.M.I. portable contamination monitor, transistorized to conserve battery power, has been developed for monitoring contamination on benches, clothing, and similar objects. Utilizing the E.M.I. dual-phosphor technique, both alpha and beta contamination can be monitored simultaneously, separate and distinctive tones being sounded on headphones or a built-in loud speaker. A meter covering the range 0-5,000 counts/sec can measure either type of contamination, or a combination of the two, by means of a single switch. For very low rates of alpha contamination, an electro-mechanical register gives a more accurate count at rates below about 6/sec.

The overall dimensions are 11¼ by 8 by 8¼ in., weight 11 lb, and the power consumption ¼ W.

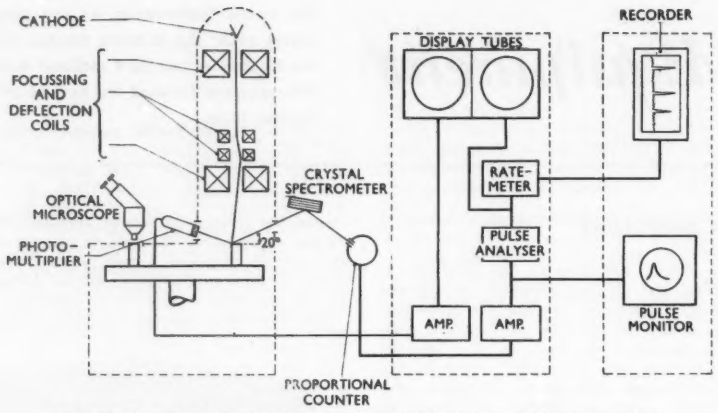
(*E.M.I. Electronics, Ltd., Hayes, Middlesex.*)

1249

X-Ray Microanalysis with Scanning Probe

Metallurgical analysis by irradiation of a minute surface with a finely-focused electron beam, and examination of the X-ray emission, originally developed in France by Mons. R. Castaing, has been extended by the scanning of the surface by the beam, so as to examine a larger area of a specimen. First developed in the T.I. Research Laboratories, and the Cavendish Laboratory, the instrument is now being marketed by the Cambridge Instrument Co.

As will be seen from the schematic diagram, the specimen is mounted on a rotating turntable, and can be located under either an optical microscope, or the electron microscope where it is scanned by an electron beam, synchronized with the scanning



Schematic diagram showing operating principles of the Cambridge scanning micro-analyser.

circuits of two display tubes. Part of the beam, reflected from the specimen, falls on the phosphor of a photomultiplier cell, and gives an electron image of the surface on the left-hand display tube. The X-ray image, displayed on the other tube, is obtained via a crystal spectrometer, the crystal being capable of rotation relative to the X-ray beam, so that it can be set to the correct Bragg angle for reflecting the characteristic emission of the chosen element through the window of a proportional counter.

The instrument has already proved itself in the examination of inclusions, the segregation of alloys, and the effect of electrodeposition of one metal on another. The area scanned is some ½ mm square at 20 kV, with a spot diameter of approximately 1 micron. Magnification of 250-3000 diameters is obtained with X-ray image resolution of approximately 1 micron, and optical resolution rather better.

(Cambridge Instrument Co., Ltd., 13 Grosvenor Place, London, S.W.1.)

1250

Radiation Shielding Material

When limitations of space do not render the use of lead essential, the choice of shielding may be governed by a number of factors.

Octagonal shield built up of Unibrix.

Unibrix, a fairly recent development, appears to offer many advantages, particularly where the shielding is to be regarded as portable. A mineral brick of high density, its interlocking chevron shape enables dry walls to be easily assembled with unskilled labour without the danger of radiation leakage due to straight joints, or the possibility of internal fissures such as might occur in bulk shielding.

Unibrix is not a cast material; the nine shapes of brick obtainable are of the pressed variety. The weights and sizes of the bricks eliminate mechanical handling. Two grades are standardized; an iron-base and a barytes-base, and the density of both grades is higher than that of barytes concrete. The wall thickness of various materials required around a 1 c source of cobalt-60, to reduce the dose rate to 0.75 mr/h, is as follows: Lead, 6½ in.; iron, 9½ in.; Unibrix I.R., 18 in.; Unibrix P.B., 21 in.; red brick, 43 in.; yellow brick, 52 in. These figures are approximate only, but will serve to give a rough comparison.

Another material of the same type, known as Uniblox, is also manufactured for permanent structures. These are of plain rectangular section, and are intended for comparatively low energies, such as the walls of X-ray rooms.

(Unibrix Radiation Shieldings Ltd., 147 Victoria Street, London, S.W.1.)

1251

Precision Pressure Switches

Designed for precision operation on pneumatic or hydraulic systems, the MPS 200 two-stage pressure switch is made in five ranges, 25-125, 50-250, 50-1500, 500-3000, and 2000-6000 p.s.i. Two settings are available in each unit, the operating tolerance being very small. For example, in a 50-250 range, the tolerance on a falling pressure is −3 p.s.i., and, if used as a single-stage switch, zero differential can, it is stated, be obtained between rising and falling pressures. Prior to final sealing, the switch is subjected to a number of functional tests, with a 2 min proof load at an appropriately increased pressure e.g., 6000 p.s.i. for the 500-3000 unit. Construction is normally in mild steel, cadmium plated, but stainless steel is used for special applications.

(M.B. Metals, Ltd., Vale Road, Portslade, Sussex.)

1252

MPS 200 precision pressure switch.

Jabroc-Cadmium Neutron Shielding

Permali " Jabroc " densified wood laminate, well known to industry, is now being manufactured with a cadmium layer for neutron shielding, the particular advantage, in addition to the 6% hydrogen content of the wood, being the mechanical strength, permitting use of the blocks without mechanical support.

Manufacture of the blocks follows normal lines, the packs of beech veneers interleaved with synthetic resin, being cured at high temperatures, and pressures around 1 ton/in.² in multi-platen presses, capable of producing sheets up to 8 ft by 4 ft or 14 ft by 16 in. Blocks thicker than 4 in. are built up from thinner sections, using laminated wood dowels and cold-setting

Cadmium-covered Jabroc blocks being covered with p.v.c.

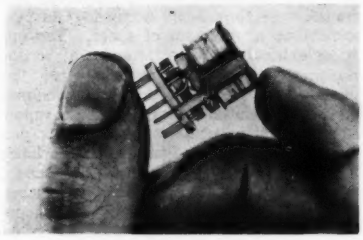
resin, under pressure of 200 p.s.i. to ensure accurate thickness. Cadmium sheet is fixed with metal pins, and an overall covering of P.V.C. sheet, sealed at the edges by hot-air welding, protects from mechanical damage.

(Permali Limited, Bristol Road, Gloucester.)

1253

Miniature Relay

Manufactured in Denmark by the Telefonfabrik Automatic A/S, and handled in Britain by Counting Instruments Ltd., a new micro-miniature relay, weighing only 11 gram, is available for portable instrument and computer work. Known as the RZO, the relay is a double-coil unit, with two changeover contacts, operated by a rotary balanced armature. Contacts are of



The RZO miniature relay.

gold-plated hard silver, with a maximum (resistive load) rating of 2A at 30V d.c. Ceramic material is used for the coil formers, to eliminate any risk of contact contamination due to outgassing. The relay is hermetically sealed, being evacuated under heat and filled with dry nitrogen. Other good features are low capacitance, and ability to withstand temperature extremes, shock, and vibration.

(Counting Instruments, Ltd., 5 Elstree Way, Boreham Wood, Herts.)

1254

Laboratory Irradiation Unit

A gamma ray irradiation unit, suitable for experimental work or small-scale radiation processing, built by Atomic Energy of Canada, Ltd., is being marketed in Great Britain by Watson and Sons (Electro-Medical), Ltd. Self-contained and easily installed, the unit has the advantages of simple operation (remote handling gear not being required), a low external radiation field, and the absence of radiation hazards in the event of mishandling.

A cylindrical sample chamber, approximately 6 in. dia by 8½ in. high, is loaded and unloaded from a position above the source, and moved into position by means of a motor. The source consists of a ring of cobalt-60 rods, mounted around a stainless steel cylinder, embedded in a shielding block. An irradiation dose rate of approximately 10^5 r/h is obtained with a source of 1100 c; the maximum source strength will depend on working conditions near the equipment, and will be between 13,000 and 30,000 c, giving dose rates around 2×10^4 r/h. Irradiation time may be pre-set.

The sample chamber has four ducts, allowing the entry of wiring, or liquids or gases, to enable irradiation in a controlled atmosphere. Overall dimensions of the unit are 40 by 60 in., by 77 in. high, the weight being 7,600 lb.

(Watson and Sons (Electro-Medical), Ltd., East Lane, North Wembley, Middlesex.)

1255

A Co-50 laboratory irradiation unit.

Parallel Jaw for Heavier Duty

The AERE remote handling equipment for standard ½ in. barrel assemblies used through balls and sockets in biological shielding has occasionally been put to uses

The new "H.L." parallel - jaw remote head.

for which it was not always suitable. A new Harwell design, for parallel operation, has been added to the "H.L." range of standard Harwell barrel and head assemblies and attachments, and has proved capable of heavier loading than previous patterns.

(H.L. Instruments, Ltd., 43 Poole Road, Westbourne, Bournemouth.)

1256

Flexible Hacksaw Blades

The superior cutting quality of high-speed steel can now be allied to the flexibility of earlier alloys, in new "Steadfast" hacksaw blades developed by J. Stead and Co., Ltd. Being hardened on the teeth only, these

This shows the flexibility of the new blade.

blades can be bent round into a complete circle, thus eliminating breakage due to unskilled labour. Made in 10-in. and 12-in. lengths, ½ in. wide and 0.025 in. thickness, the saws can be obtained with tooth pitches of 32, 24, 18 and (in the longer blades only) 14 t.p.i. at normal high-speed steel blade prices.

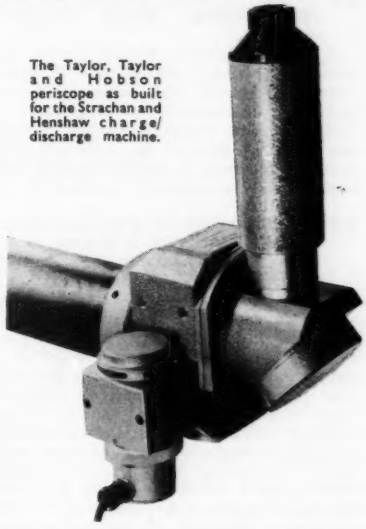
(J. Stead and Co., Ltd., Manor Works, Cricket Inn Road, Sheffield, 2.)

1257

New Viewing Periscope for Fuel Elements.

Stabilized lenses are incorporated in a new periscope, manufactured by Taylor, Taylor and Hobson, for viewing "hot" fuel elements, and incorporated in the Strachan and Henshaw charge/discharge machines for Bradwell and Latina.

The Taylor, Taylor and Hobson periscope as built for the Strachan and Henshaw charge/discharge machine.



Each periscope consists of two independent optical systems, one for illumination, with the lamp accessibly positioned at the outer end and a series of relay lenses to illuminate an area of some 4 in. diameter at 10 in. distance, and the viewing system, which provides a full-size image at the eyepiece, approximately 6 ft. from the object. Construction is in 4½-in. steel tube, chromium plated inside and out, and the unit, designed for operation at 150 p.s.i., at temperatures of 200°F, weighs some 180 lb.

To guard against darkening under the intense gamma radiation, the lenses are ground from Chance-Pilkington stabilized glass (i.e., containing cerium oxide). The general properties of this glass were reviewed in *Nuclear Engineering* for August, 1957 (pp 315 and 333).

Each of the Strachan and Henshaw charge/discharge machines incorporates three periscopes, one being fitted with Pye closed-circuit television.

(Taylor, Taylor and Hobson, Ltd., Stoughton Street, Leicester.)

1258

Infra-Red Security Detector

A security "barrier" for warning of unauthorized intrusion, which will operate up to 550 yards, is the Briticent DT4 infra-red detector, recently marketed. It consists of three units, a modulating projector, a receiver, and a detector-contactor unit, all three housed in weatherproof aluminium alloy housings. The projector, which is arranged for 240 V single-phase supply, has a motor-driven shutter, which modulates the light output some 700 times a second, and the receiver is tuned to the same frequency, thus preventing unwanted operation due to snowflakes, headlamps, lightning flashes, etc. The lens diameters are 45 mm.

(British Central Electrical Co., Ltd., 6 and 8 Rosebery Avenue, London, E.C.1.)

1259

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 811,782. Ceramic materials for radiation shielding. Plessey Co. Ltd. (U.S.A.).

A sintered mixture formed wholly or mainly of barium oxide or one or more compounds thereof with non-metallic elements and of lead oxide or compounds of lead oxide, the molecular barium content exceeding one third of the molecular lead content. Mixtures of barium sulphate and lead silicate are especially satisfactory.

B.P. 811,790. Vessels for processing nuclear fuel. R. T. Ackroyd, D. Kenyon, D. F. Abel and U.K. Atomic Energy Authority.

Details are given of a double-walled vessel designed for the dissolution of irradiated highly enriched fuel elements avoiding the risk of the accumulation of a super-critical mass of the fuel in the process. The vessel is of nearly cylindrical shape, closed at both ends. A tube in the (vertical) axis of the vessel is connected with the interspace between the tube walls and is surrounded by a jacket, through which steam is passed for heating purposes. The space between tube and inner wall of the vessel is filled with a moderator material such as borated graphite. The fuel elements to be processed are lowered into the central tube via a funnel. Subsequently nitric acid is fed into the tube, which, as a result of the heat, circulates naturally through the tube and the wall interspace. On completion of the dissolution the liquid is drained off.

B.P. 811,841. Uranium alloys. N. P. Allen, J. D. Grogan and U.K. Atomic Energy Authority.

Extremely pure uranium is liable to excessive distortion on repeated heating and cooling which makes it impossible to calculate its physical behaviour in operation. This drawback can be overcome by adding an alloying element or elements (aluminium, silicon, phosphorus, tin, lead, bismuth, niobium, zinc) of small neutron capture cross section in amounts not less than 0.05% of the uranium (by weight) but low enough not to increase the total thermal neutron absorption more than 0.1%.

B.P. 811,856. Nuclear plant. W. Macrae and C. A. Parsons and Co., Ltd.

The temperature of the cooling fluid leaving the reactor to circulate through the heat exchanger, and the pressure of the working fluid leaving the heat exchanger to pass to the power plant, are maintained constant. The temperature is controlled by varying the speed and the amount of cooling fluid passing through reactor and heat exchanger. The pressure changes in the working fluid vary the position of the control rods in the reactor.

B.P. 812,004. Nuclear reactors. R. A. Kline, W. Macrae and C. A. Parsons and Co., Ltd.

A novel arrangement of the sampling tubes feeding burst slug detectors associated with a reactor is described. A separate sampling duct for each cooling channel is provided in the charging pans. Tubes connected to the sampling ducts in the charging pans extend through the corresponding charge duct in the top of the biological shield up to a point about half-way through the thickness of the top layer of the concrete shield, where they are joined to a selector mechanism positioned in a cavity in the shield. The latter mechanism continuously selects a gas sample from one tube at a time and passes this sample through a single pipe to a further selector mechanism situated outside the biological shield. This second selector mechanism, receiving continuously similar samples from other parts of the reactor, selects, in turn, one sample at a time from those received through its own feeder pipes, for transmission to the sensitive element of the detector instrument. The essential advantage of the present arrangement is the reduction of the number of pipes passing through the concrete shield compared with conventional systems. The system is suitable for use with gas- or liquid-cooled reactors.

B.P. 812,122. Method of electromagnetically separating ionic isotopes. U.K. Atomic Energy Authority.

Essentially, the equipment required consists of two chambers. In the first, the vapours containing the isotopes—uranium halide—are raised and passed to the second, at a higher temperature than the first. An electric arc is passed through the latter chamber, ionizing the vapours present. The ions are collected and separated according to their mass while moving through a magnetic field.

B.P. 812,195. Electromagnetic pumps. L. R. Blake, and British Thomson-Houston Co., Ltd.

Reference is made to the a.c. conduction electromagnetic pump which is used for the pumping of liquid metals. In such pumps, the liquid in the duct, along which it is to be moved, is exposed to a transverse alternating electromagnetic field having the same frequency as an alternating current crossing the liquid in a direction transverse to both the duct and magnetic field. At a suitable relative phasing of the alternating current mentioned last and the field, the liquid is caused to move along the duct. The present invention achieves greater compactness of the construction of these pumps by providing an arrangement facilitating the use of one current source only for both the alternating current crossing the liquid and that establishing the magnetic field.

B.P. 812,544. Atomic piles. U.K. Atomic Energy Authority (Canada).

Normally, a fission reactor consists of a core and a reflector surrounding the same. In this arrangement the heat output of the reactor varies from a maximum at the centre of the core to a minimum, possibly zero at times, on the periphery of the core. As a result the average rate of power produced per unit weight of fissile material across the core is low. It is the aim of the present invention to obtain an improvement of this condition by the provision of a reflector inside the core in addition to the conventional reflector on the periphery of the core. In a particular embodiment of the invention the internal reflector is located in the axis of the core. A still higher average rate can be obtained if heterogeneous reflector structures are employed embodying material such as thorium or depleted uranium which becomes fissile under neutron bombardment, supported and surrounded by a moderator material.

B.P. 812,500. Vapour generating unit. Babcock and Wilcox Co. (U.S.A.).

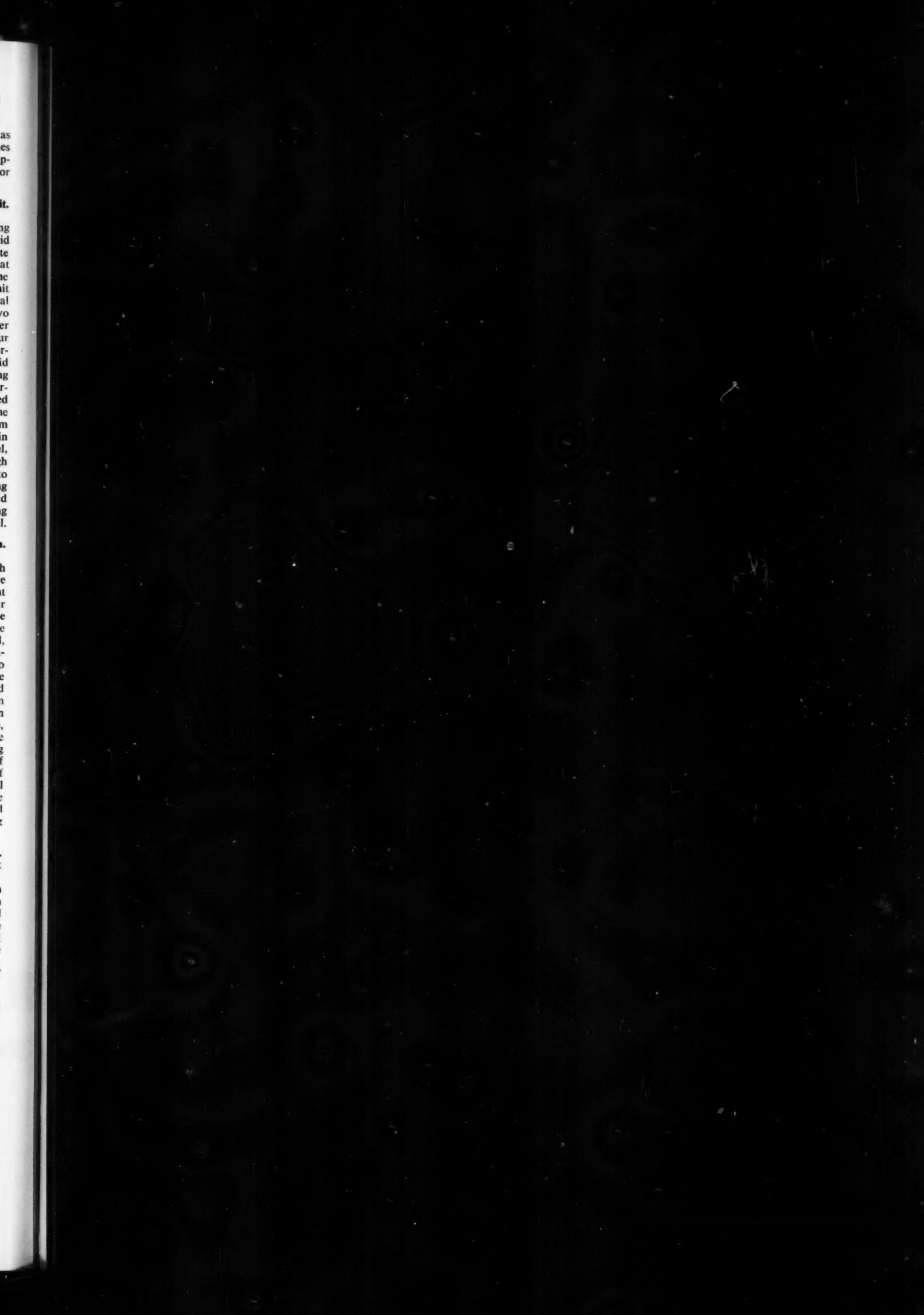
Details are given of a vapour generating unit, where the heating fluid could be liquid metal, water or gas, etc., which is to operate as a heat exchanger with an improved heat transfer performance, occupying at the same time a minimum of space. The unit is cylindrical and operates in a vertical position. It consists essentially of two chambers, the vapour generating chamber forming the lower portion and the vapour separating chamber forming the upper portion of the vessel, the surface of the liquid separating the two chambers. The heating fluid is conveyed through the vapour generating chamber in a plurality of U-shaped tubes located in a reverse position in the steam generating chamber. The wet steam enters whirl chamber separators arranged in a ring in the upper chamber of the vessel, the dry steam leaving the vessel through ducting, and the water being returned to the bottom portion of the vapour generating chamber through an annular space formed by plates surrounding the vapour generating section and the walls of the pressure vessel.

B.P. 812,591. Radioactive measuring system. Foxboro Co. (U.S.A.).

Radioactive measuring instruments such as beta-ray gauges, employed for instance for the determination of basis weight variations in paper, depend for their accuracy on a precise knowledge of the length of the air gap in which the sample is placed. This dimension may be affected, however, by changes in temperature, vibration, handling or impact. In order to eliminate the effects of a possible change in the length of the air gap it is proposed to pass the sample under two radiation sources each operating in conjunction with an ionization chamber of its own, one source, such as thallium, emitting soft rays, and the other source, such as strontium-90, emitting hard radiation. The absorption effect of the sample is different for the two types of radiation and, by arranging for differential measurement, an accurate value of the variable to be determined can be obtained independently of the air gap length so long as the latter is the same for both set-ups.

B.P. 812,682. Recovery of ruthenium. W. E. Grummitt, W. H. Hardwick (Canada).

Ruthenium isotopes are recovered from residual aqueous solutions (from dissolution of neutron-irradiated uranium in nitric acid and treatment of the acid solution for the recovery of uranium) by adjusting the pH of the solution to 1-3 and oxidizing the ruthenium isotopes to the octavalent state. The isotopes are then extracted by means of a liquid halogen-substituted paraffin.

B.P. 812,701. Production of radioactive phosphorus. Institutt for Atomenergi (Norway).

Sulphur is irradiated with neutrons and the irradiated sulphur extracted in the solid state in finely divided form at a temperature at or above which sulphur is transformed from the rhombic to the monoclinic form (transition point 95.5° C) using an aqueous extraction agent having a solvent action on the phosphorus at that temperature. The residual undissolved sulphur is then separated.